Executive summary

Introduction

The forecasting of demand is critical to those involved in water resources planning. These forecasts help managers assess the adequacy of the present resources to meet future demands. Since the time required is lengthy to build new resources or implement demand management strategies, forecasts of future demands help managers and municipalities to plan for the future.

The study was conducted in two parts. The first study element provides an estimate of the Washington metropolitan area (WMA) water supply demands in the year 2020. The second major study element shows how the current system of rivers and reservoirs functions while meeting estimated future demands. The main focus of the study is to assess the ability of the regional water resources to meet the water supply needs of the WMA population as it continues to increase.

Background

The majority (approximately 90 percent) of the WMA's population relies on water furnished by three agencies:

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

These agencies supply treated water either directly to customers or through wholesale suppliers. The three major 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 in periods of low flow. This cooperative work is coordinated by a special section of ICPRB, called the "Section for Cooperative Water Supply Operations" (CO-OP).

The study applies to the Washington metropolitan area CO-OP member water suppliers and their wholesale customers. The 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.

The natural flow in the Potomac River supplies approximately 75 percent of the water supply withdrawals in the WMA, with the remainder supplied by FCWA's Occoquan Reservoir and WSSC's Patuxent reservoirs. The Potomac is the sole source of supply for the Aqueduct. All three suppliers contribute to the cost of construction and operation of two reservoirs (Jennings Randolph and Little Seneca) in the Potomac River basin which are used for low flow augmentation.

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 that “In April 1990 and in April of each fifth year thereafter ... the Aqueduct, the Authority, the Commission and the District shall review and evaluate the adequacy of the then available water supplies to meet the water demands in the Washington Metropolitan Area which may then be expected to occur during the succeeding twenty year period.” At their meeting of April 28, 1999, the parties to the LFAA directed the ICPRB’s CO-OP Section to conduct the required review and evaluation of demands and supplies. This report is the third of three such reports prepared by ICPRB.

Demand projection

The estimate of future demands is based on three types of water uses, namely single family household use, multi-family (apartment) water use, and employee water use. Projections of numbers of households and employees were based on the Metropolitan Washington Council of Governments (MWCOG) employment and household projections, which were collaboratively developed by MWCOG and local government planners and demographers. 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 estimates of the number of each type of water user and the coefficients describing average water use for each jurisdiction.

Estimates of future demand developed for this study take into account several factors that can affect future demand. Per household water use was assumed to be lower in the future than it is today as a result of the *Energy Policy Act of 1992*. Seasonal water use patterns were used to convert the forecast of annual average demand into summertime peak use estimates. High estimates of future growth were used as an alternative basis on which to predict future demand. An estimate was made of unaccounted/unmetered water use for each jurisdiction. The impacts of potential climate change on future demand were examined.

Resource analysis

The resource analysis examines the existing water system’s ability to meet future demands. The operation of the water resource system is modeled so that the Occoquan and Patuxent reservoirs are used sustainably, and Jennings Randolph and Little Seneca reservoirs are used to augment low flows in the Potomac River.

As part of the resource analysis developed in this study, several factors that can affect future resources were examined. Emergency demand reduction strategies, i.e., voluntary and mandatory restrictions were modeled. (Voluntary restrictions were assumed when combined Jennings Randolph and Little Seneca reservoir storage was less than 60 percent full, and mandatory restrictions were assumed when either reservoir storage was less than 25 percent full.) The effects of siltation on reservoir storage over time were incorporated into the analysis. Increasing return flows from wastewater treatment plants upstream of the Potomac water supply intakes and Occoquan Reservoir were included. The current recommended environmental flow rate for Little Falls was included. The efficiency of a Jennings Randolph release was investigated and included. (Not all water released from Jennings Randolph is used as water supply due to the inability to make perfect forecasts of demand and river-flow 9 days ahead of time, which is the travel time of a Jennings Randolph release to the water supply intakes.) The effects of climate change on resources were investigated. The effects of upstream consumptive demand on historical streamflow resources were included.

Results

Under the most likely population growth scenario, demands will increase by approximately 100 mgd for the CO-OP utilities from a current average annual water use of 480 mgd to 579 mgd, an increase of 21 percent. The high growth scenario results in an increase of annual water use from 480 mgd to 606 mgd, an increase of 126 mgd or 26 percent.

Although the MWCOG population forecast was for the year 2020, the forecast was extended to the year 2040 by assuming a continuation of similar rates of growth. This extension allowed 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 2020 horizon is a rough approximation.

A range of demand forecasts was compared with the available resources. Assuming a repeat of the drought of record, the following results were obtained:

- Using the *most likely* growth scenario, current resources met 2020 levels of demand with about 20 percent reserve storage in the Potomac reservoirs.

- Using the *most likely* growth scenario, current resources met 2030 levels of demand with about 10 percent reserve storage in the Potomac reservoirs.

- Using the *high growth* scenario, current resources met 2020 levels of demand with about 15 percent reserve storage in the Potomac reservoirs.

- Using the *high growth* scenario, current resources met 2030 levels of demand with about 1 percent reserve storage in the Potomac reservoirs.

Additional results were obtained from an investigation of model sensitivity analyses:

- Storage in the Potomac reservoirs was nearly depleted given the *most likely* forecast of 2020 demands and a reduction in streamflow resources of ten percent.

- The potential effects of climate change on resources were investigated but were not explicitly included because there was a lack of any clear climate change result for this region’s resources.

- If climate change were to occur, demands could increase and streamflow resources could decrease relative to historical conditions. Resource sensitivity analysis indicates that given a reduction in historical streamflow of 5 percent and a 9.5 percent increase in June through September demands, the system of reservoirs could meet *most likely* 2020 demands but reserve storage would be nearly depleted.

- The average annual demand for the WMA is forecast to increase by approximately 100 mgd for the *most likely* scenario and approximately 126 mgd for the *high growth* scenario in the year 2020. Sensitivity analysis shows that the current system of reservoirs would be able to meet an increase in average annual demand of up to 150 mgd under a repeat of 1930-1931 flow conditions.

Conclusions

Two demand forecasts (*most likely* and *high growth* scenarios) were compared with the available resources. Assuming a repetition of the drought of record the following conclusions can be made:

- The current system of resources is adequate to meet the *most likely* and *high growth* estimates of 2020 demands even if the worst drought of record was to be repeated.

- Storage in the Potomac reservoirs was depleted given demands in excess of the *high growth* forecasts for 2030.

- Reserve storage in the Potomac reservoirs was sensitive to small reductions in the historical streamflow data.

- Climate change may have an impact on resources that would change the study results, especially given the sensitivity of Potomac reservoir storage to changes in historical streamflow data. Uncertainty in the current state of knowledge of future climate change precludes an acceptable forecast of what the effect on resources might be.

- Because of the current uncertainty and magnitude of impact of the potential effect of climate change on resources, future demand and resource studies might consider: 1) an examination of how extreme droughts might be influenced by potential climate change, and 2) a stochastic analysis to quantify the risks of experiencing a drought that is more extreme than historical observed droughts.

- A change in the minimum environmental flow rate might affect the results of the resource availability analysis.

- Demand forecasts could be higher than those used in the study if Congress repeals the *Energy Policy Act of 1992*, although local plumbing codes would control fixture ratings and may retain the conservation requirements contained within the Act for some jurisdictions.

Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area

Prepared by

Erik R. Hagen
and
Roland C. Steiner

October, 2000

The Section for Cooperative Water Supply Operations on the Potomac

Interstate Commission on the Potomac River Basin
6110 Executive Boulevard, Suite 300
Rockville, Maryland 20852

Report No. 00-6

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 Washington Suburban Sanitary Commission, the Washington Aqueduct Division of the U.S. Army Corps of Engineers, and the Fairfax County Water Authority. 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 utilities.

Preface

On January 11, 1978, the governments of the United States, District of Columbia, Maryland, Virginia, and the Chairmen of the Fairfax County Water Authority and the Washington Suburban Sanitary Commission committed their constituencies to a historic agreement which allocated low flows in the Potomac River. For more than twenty-two years, the Potomac River Low Flow Allocation Agreement (LFAA) has not had to be implemented; however, in preparation for that possibility, the signatory parties have met during the Spring of each year since its ratification in order to affirm its principles and approve data upon which its implementation would be based.

Modification No. 1 to the LFAA indicates that article 2.c. include the following requirement: "In April 1990 and in April of each fifth year thereafter… the Aqueduct, the Authority, the Commission and the District shall review and evaluate the adequacy of the then available water supplies to meet the water demands in the Washington metropolitan area which may then be expected to occur during the succeeding twenty year period." At their meeting of April 28, 1999, the parties to the LFAA requested the Section for Cooperative Water Supply Operations on the Potomac (CO-OP) of the Interstate Commission for the Potomac River Basin (ICPRB) to conduct the required year 2000 review and evaluation of the demands and supplies.

The following report discusses the methods and assumptions used to determine demands and resources, and presents the results and conclusions of that analysis.

We would like to thank all those people who contributed their time and expertise in reviewing the study final report, attending the public information meetings, and providing data for use in the study. Without the contributions of so many people, this report would not have been possible.

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Results

Under the most likely population growth scenario, demands will increase by approximately 100 mgd for the CO-OP utilities from a current average annual water use of 480 mgd to 579 mgd, an increase of 21 percent. The high growth scenario results in an increase of annual water use from 480 mgd to 606 mgd, an increase of 126 mgd or 26 percent.

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1 Study objective and background

1.1 Objective

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The objective of this study is to forecast the water supply demands for the year 2020 and to assess the ability of the regional water resources to meet the growing water supply needs of the Washington metropolitan area (WMA) population.

1.2 Water suppliers

The majority (approximately 90 percent) of the WMA's population relies on water furnished by three agencies:

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

1.3 History of cooperation

The three major agencies cooperate on water supply operations in the Potomac, essentially operating as one entity in sharing water across the Potomac, Patuxent and Occoquan basins in periods of low flow. This cooperative work is coordinated by a special section of ICPRB, called the "Section for Cooperative Water Supply Operations" (CO-OP).

The first regional approaches to water supply management began in the 1960s, when concern began to surface that projected growth in the region would eventually lead to a demand for water in excess of available supply. This concern was heightened by drought conditions in the mid-1960s; at one point in the summer of 1966, flow in the river was less than projected future demands.

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. There was significant public opposition to many of these sites; only one, Jennings Randolph Reservoir near Bloomington, Md., was ever built.

At the same time, the three utilities realized that management of the river during low flows would be required to meet demands as the region grew. Research begun 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 demands well into the next century. The research suggested that if the water supply agencies could coordinate their actions in and outside the basin, then the region's projected demands for the next 25 to 50 years could be met with only a fraction of the reservoir storage proposed by the Corps.

A regional consensus emerged that minimized the need for new dams or other costly, controversial structural measures. The key agreements governing this cooperative approach were forged at this time:

- In 1978, the states and the water supply agencies signed the Low Flow Allocation Agreement, which allocates the amount of water each agency can withdraw from the river when total flow is not sufficient to meet all needs.

- In 1982, the water supply agencies and ICPRB signed the Water Supply Coordination Agreement (WSCA). This agreement provides for coordination of all the major supply facilities in the region, including those on the Patuxent and Occoquan rivers, so as to minimize the potential for flows to reach such low levels in the Potomac that the LFAA's allocation mechanisms would be triggered. The WSCA also describes the major functions of the CO-OP Section within the ICPRB.

The major water supply agencies 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 furnish over 17 billion gallons to augment naturally occurring flows in the Potomac.

In the WSCA, the utilities gave CO-OP a direct role in managing water supply resources and withdrawals in the Washington metropolitan area. The agreement provides for an Operations Committee, consisting of representatives from the Aqueduct, FCWA, 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 utility realized that by cooperating to make operating decisions, each could meet their demands and collectively meet the demands of the region.

The three regional water suppliers' decision to seek a joint solution to the water supply shortage through ICPRB has made it possible to provide an adequate water supply for the Washington metropolitan area. The means of achieving this end not only satisfy the water demands; they are hundreds of millions of dollars less costly than previously proposed courses of action.

The summer of 1999 marked the first year that stored water has been used to augment the natural flow of the Potomac River for water supply purposes. Cooperative operations among the Interstate Commission on the Potomac River Basin (ICPRB) and the area's three major water utilities ran smoothly, and the augmented flow of the Potomac provided all the water required by the utilities. ICPRB report number 99-6 describes in more detail the actual operations of the CO-OP section and the three utilities during the drought of 1999.

2 General description of the WMA water supply system

2.1 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. These include the CO-OP suppliers (the Aqueduct, FCWA, and WSSC) and the wholesale customers that are provided with treated water by the CO-OP suppliers. This forecast also includes the City of Rockville, Maryland. The CO-OP suppliers and their wholesale customers together provide water to over 3.6 million of the WMA area residents.

Figure 2-1 shows an overview of the CO-OP study area and resources. The non-tidal Potomac River as well as the Occoquan and Patuxent reservoirs provide the source water for the three CO-OP utilities. The WSSC serves the Maryland suburbs; the Aqueduct sells water to wholesale customers in DC and portions of Virginia; and the FCWA 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.

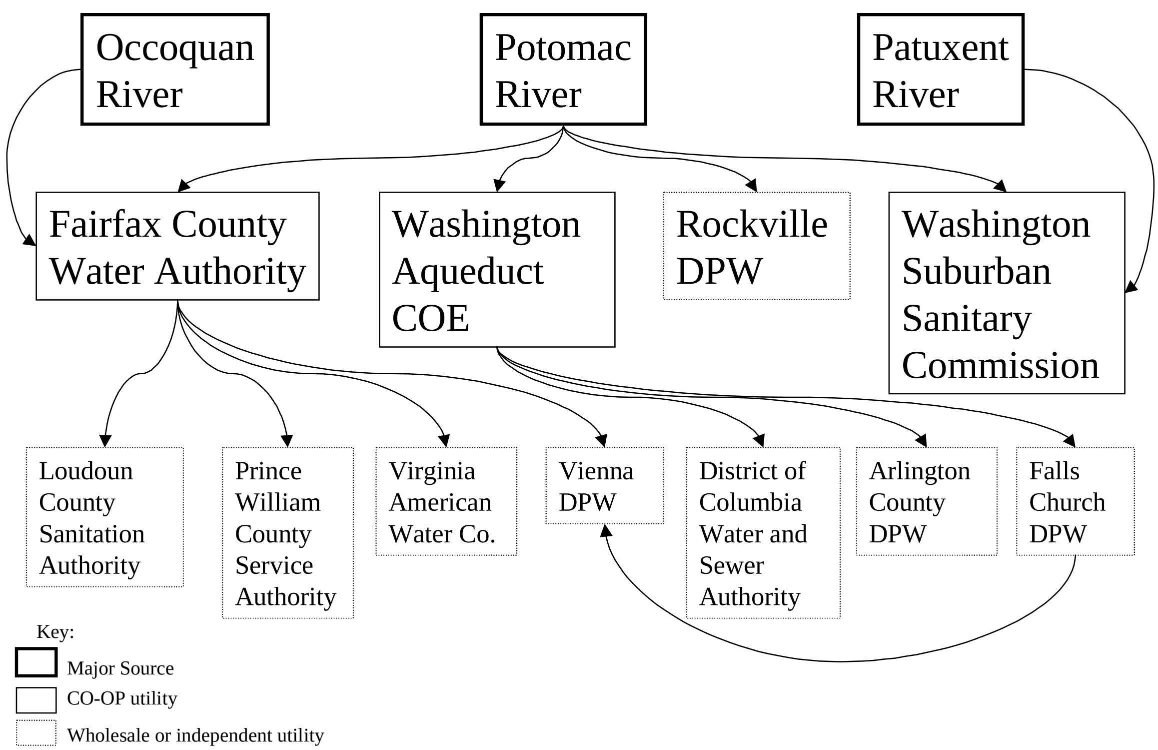

Figure 2-1: Schematic of study area and resources

2.2 WMA water resources

Most of the residents of the Washington metropolitan area 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 CO-OP suppliers. The two suburban utilities own reservoirs that do not fill from the Potomac that 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 following are the major components of the metropolitan water supply system:

2.2.1 Shared resources

- **Jennings Randolph Reservoir.** This reservoir is the area's "savings account." It holds 13.4 billion gallons (bg) of water supply storage that is available to the three utilities. Releases are directed by ICPRB CO-OP based on existing and projected utility demand, status of other reservoirs, and weather conditions. The reservoir is some 200 miles upstream of the utilities' intakes, and releases take more than a week to travel to them during times of low flow. The catchment area of Jennings Randolph is about 263 square miles.
- **Little Seneca Reservoir**. This smaller reservoir, which stores 3.8 bg that is owned by the three utilities, is used to "fine tune" the larger releases from Jennings Randolph, which then can be operated more conservatively. Located in Montgomery County, Md., releases take less than a day to reach the utilities' intakes. Little Seneca's catchment area is about 21 square miles.

2.2.2 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. The utility uses this stored water in tandem with Potomac withdrawals throughout the year. The catchment area of these reservoirs is about 132 square miles.
- **Occoquan Reservoir**. The FCWA 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 catchment area of the Occoquan is about 592 square miles.

The system of CO-OP reservoirs is shown in Figure 2-2.

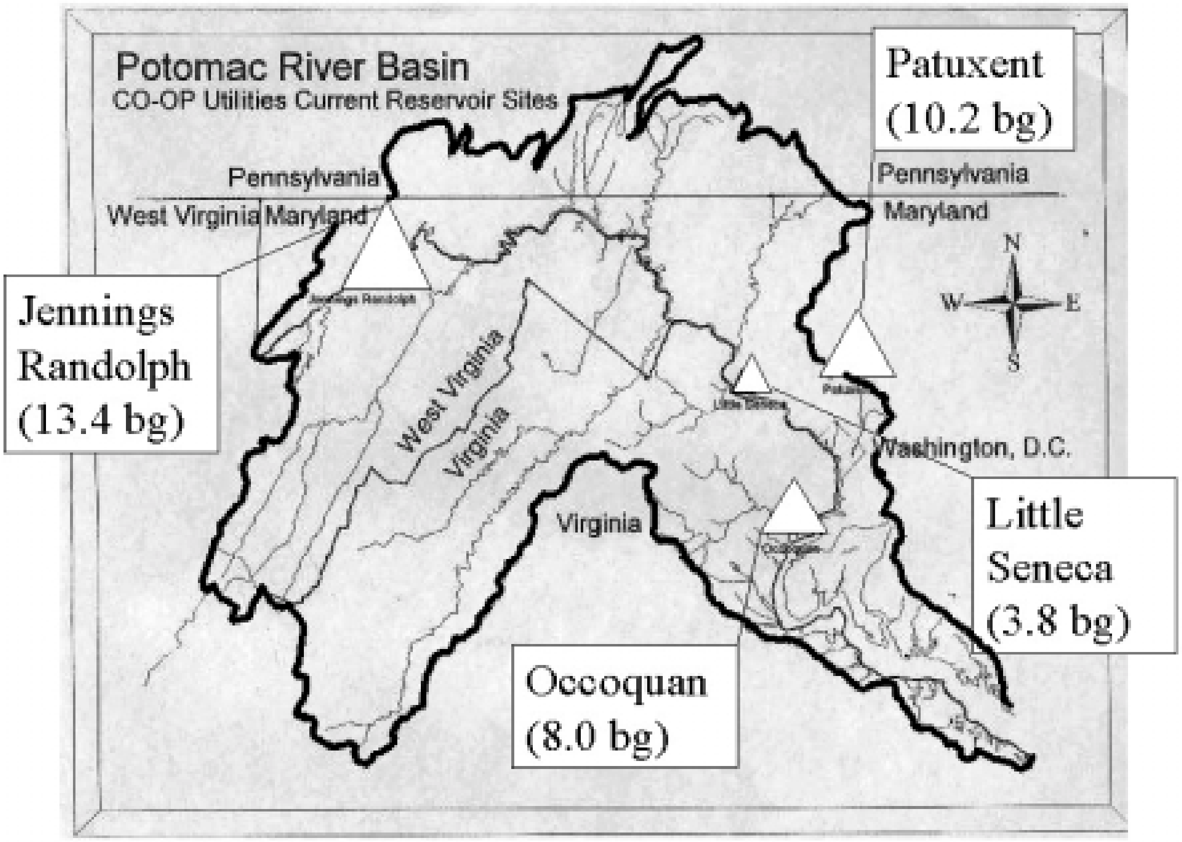

Figure 2-2: CO-OP utility reservoir sites

2.2.3 The Potomac River

The Washington metropolitan area depends primarily on the non-tidal Potomac River for most of its water. Potomac River flow is usually higher in the winter months and lower in the summer months. Demands are potentially higher than Potomac flow for only a relatively short period of time (four months) from about mid-July through early-November. This time period is when Potomac augmentation releases are most likely to occur given current demands. Because the critical analysis period for comparing demands to resources is during the summer through fall, it is important to accurately develop an estimate of how demands might look in the summer through fall of 2020.

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 utilities on the river is about 500 million gallons per day (mgd), or 0.5 bgd.

2.3 CO-OP utilities

In terms of volume of water treated, the Aqueduct and WSSC are approximately equal in size, treating an average of 183 million gallons per day (mgd) and 168 mgd in 1999, respectively. On average, FCWA treated 135 mgd in 1999. In 1999, 22 percent of

WSSC's production came from the Patuxent reservoirs and 43 percent of FCWA's production came from the Occoquan Reservoir.

WSSC's peak production of 267.3 mgd occurred on July 8, 1988. FCWA's peak production of 220.7 mgd occurred on June 9, 1999. The Aqueduct's peak production of 281.1 mgd occurred on July 7, 1999. The combined maximum peak production of FCWA, WSSC, and the Aqueduct of 741.1 mgd occurred on June 8, 1999. The combined FCWA, WSSC, and Aqueducts' average annual and peak daily production over the period 1974-1999 is shown in Figure 2-3 (ICPRB data incomplete for 1989, 1990).

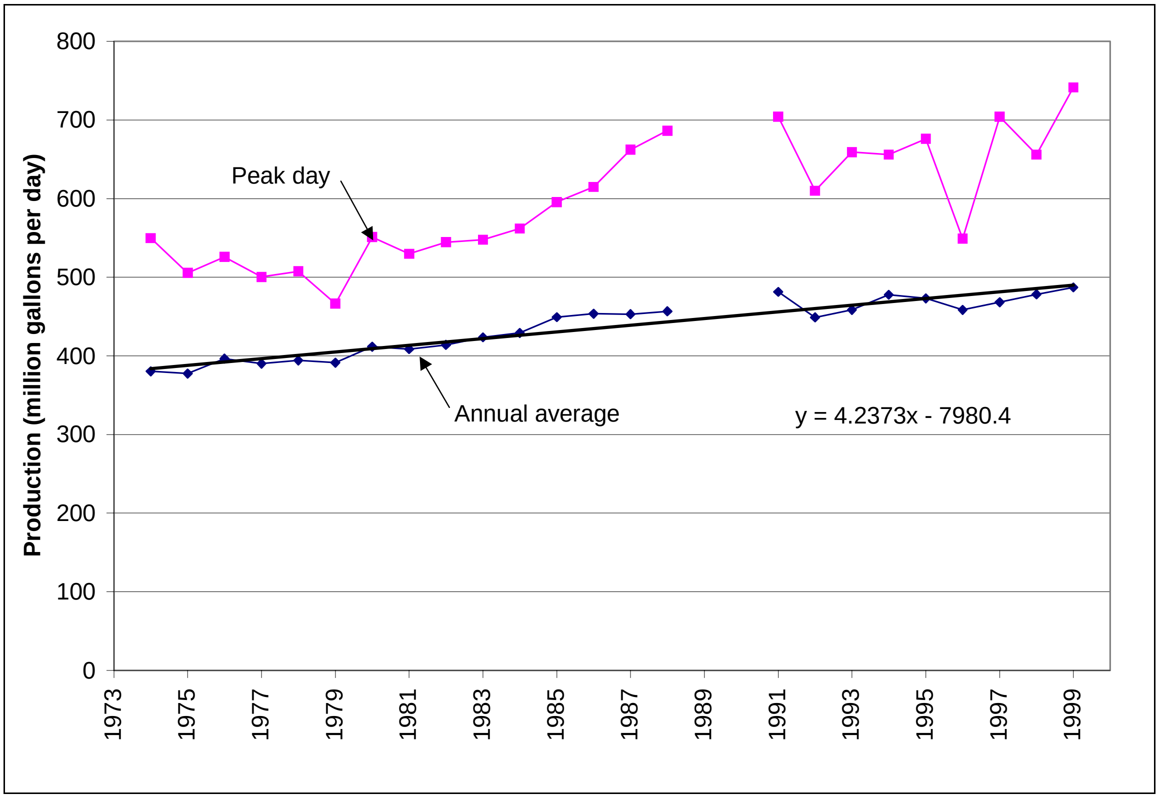

Figure 2-3: WSSC, the Aqueduct, and FCWA annual average and peak day demand

Figure 2-3 shows that the peak day demand can be significantly greater than the annual average demand. For the period 1991 through 1999, the peak day demand was on average 29 percent higher than the annual average demand and a maximum of 50 percent higher than the annual average demand (1999).

Figure 2-4 shows the CO-OP water supply intakes on the Potomac River. WSSC maintains a shoreline intake near Potomac, Md., to supply its Potomac treatment plant. To supply its Corbalis water treatment plant, FCWA maintains a shoreline intake on the Virginia side of the Potomac River just downstream of its confluence with Sugarland Run. The Aqueduct has intakes on the Maryland shore at both Great Falls and Little Falls.

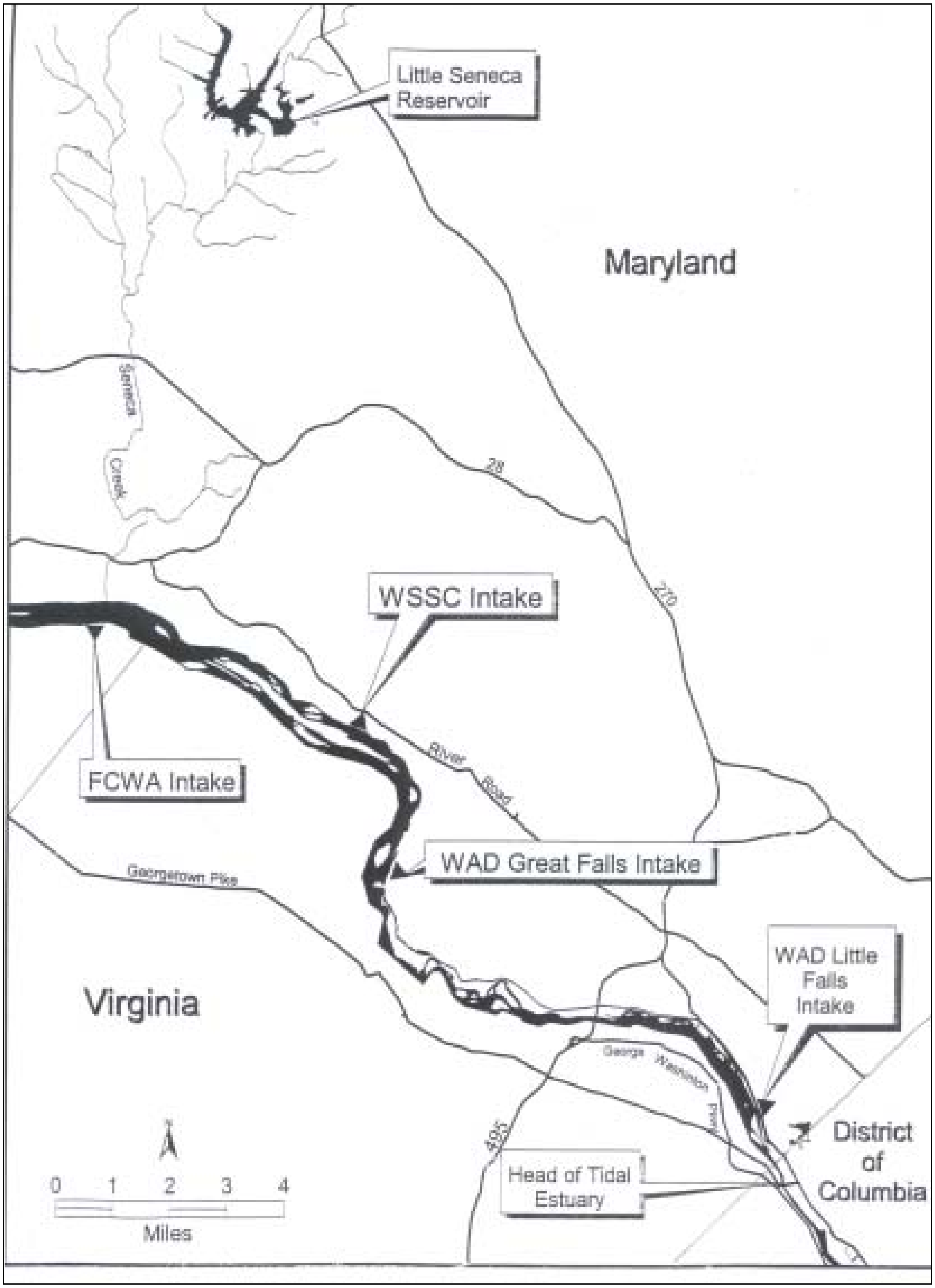

Figure 2-4: CO-OP system Potomac intakes

3 Current patterns of water production for the CO-OP Suppliers

3.1 Introduction

This chapter describes current water production patterns of the CO-OP suppliers. This chapter describes the algorithm used to relate average annual demand, a single number, to a dataset of daily demands that vary by season. The dataset of daily demands was used to run the daily Potomac System River and Reservoir Model (as described in Chapter 6) to determine the adequacy of supplies to meet future demands.

The disaggregation of the predicted 2020 annual average demand to a set of daily demands requires an analysis of current water production patterns in order to capture the daily and seasonal variations in demand. Production data for the Aqueduct, FCWA, and WSSC over the years 1991 through 1999 was analyzed.

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 shows the *average* daily water production for the three CO-OP utilities over the period 1991 through 1999. Average production ranged from a low of about 400 mgd in winter up to a high of approximately 600 mgd in the summer. Note that Figure 3-1 shows average daily demand over a 9-year period, and that peak daily demand in any given year can be higher.

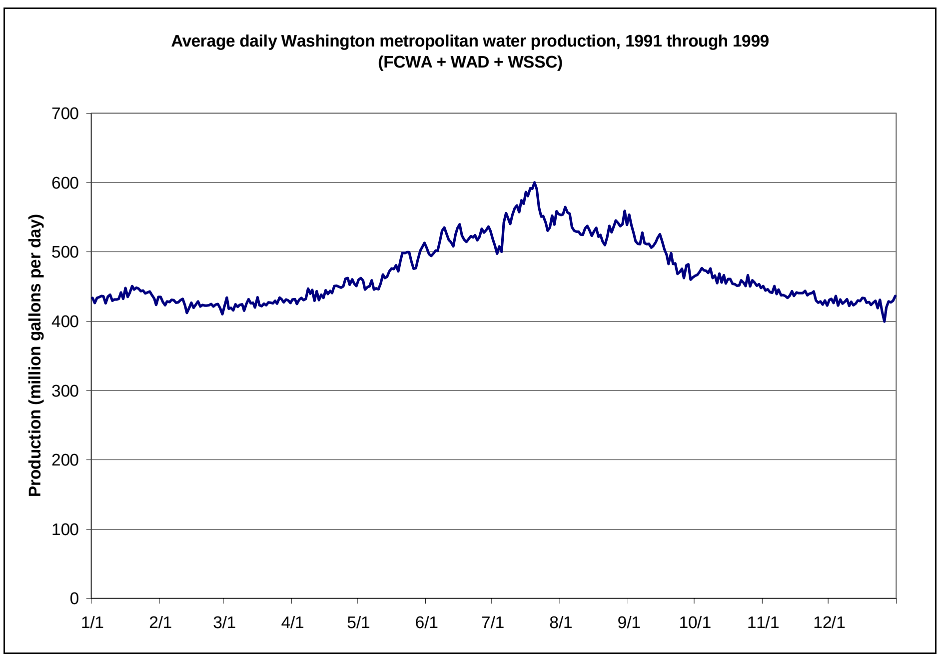

Figure 3-1: Average daily WMA production, 1991-1999 (FCWA + Aqueduct + WSSC)

3.3 Patterns of recent monthly water production

Mean monthly production factors were used in prior studies to disaggregate forecasts of average annual demand to monthly average demands. The factors reflect seasonal water use patterns within each water supply system. Ratios of monthly average production to annual average production were calculated for each year of data for each utility and for the CO-OP system (Appendices A through D). The average of these monthly production factors is called the "mean monthly production factor," so deftly named. The mean monthly production factor for each month for each of the CO-OP suppliers and the CO-OP system total is shown in Table 3-1.

Table 3-1: Mean monthly production factors for WSSC, FCWA, the Aqueduct, and the CO-OP system total, calculated from 1995-1999 production data.

	WSSC	FCWA	Aqueduct	CO-OP total
January	0.95	0.86	0.95	0.93
February	0.93	0.85	0.93	0.91
March	0.93	0.86	0.93	0.91
April	0.96	0.93	0.94	0.94
May	1.02	1.02	0.97	1.00
June	1.08	1.13	1.03	1.08
July	1.14	1.23	1.15	1.17
August	1.12	1.25	1.14	1.16
September	1.05	1.10	1.06	1.07
October	0.97	0.97	1.00	0.98
November	0.94	0.91	0.95	0.93
December	0.92	0.88	0.93	0.91

Table 3-1 shows that the CO-OP system demand is highly variable over the season. July and August are the peak system months in which average 1995-1999 monthly demand is 1.17 and 1.16 times the average annual demand, respectively.

In addition to monthly average production and monthly average production factors, Appendices A through D also show peak 1-day production, peak 1-day production factors, peak 7-day production for each month, peak 7-day production factors, average July 1 through October 31 production, and July 1 through October 31 production factors. These factors were developed in a manner similar to the monthly production factors. The peak 7-day production factor is the ratio of the peak 7-day monthly production divided by the average monthly demand. The July 1 through October 31 production factor is the ratio of the July 1 through October 31 production divided by the annual average production.

3.4 Converting average annual demand to a dataset of daily variable demands

This section presents the algorithm used to relate average annual demand, a single number, to a dataset of daily variable demands.

3.4.1 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 demands, in which demands are constant for 3 weeks, then are stepped up to a higher constant value for six days, and finally peak for a period of one day. Although this approach is no longer being used to develop the daily demand dataset, Figure 3-2 illustrates what this demand data would have looked like for an average annual demand of 486 mgd (1999). In order to provide continuity with the prior reports, these demand factors were calculated for each utility and for the CO-OP system. Appendices A through D provide detailed summaries of daily, 7-day, 120-day, and monthly production factors calculated from the 1995 through 1999 time period for the Aqueduct, FCWA, WSSC, and for the system total.

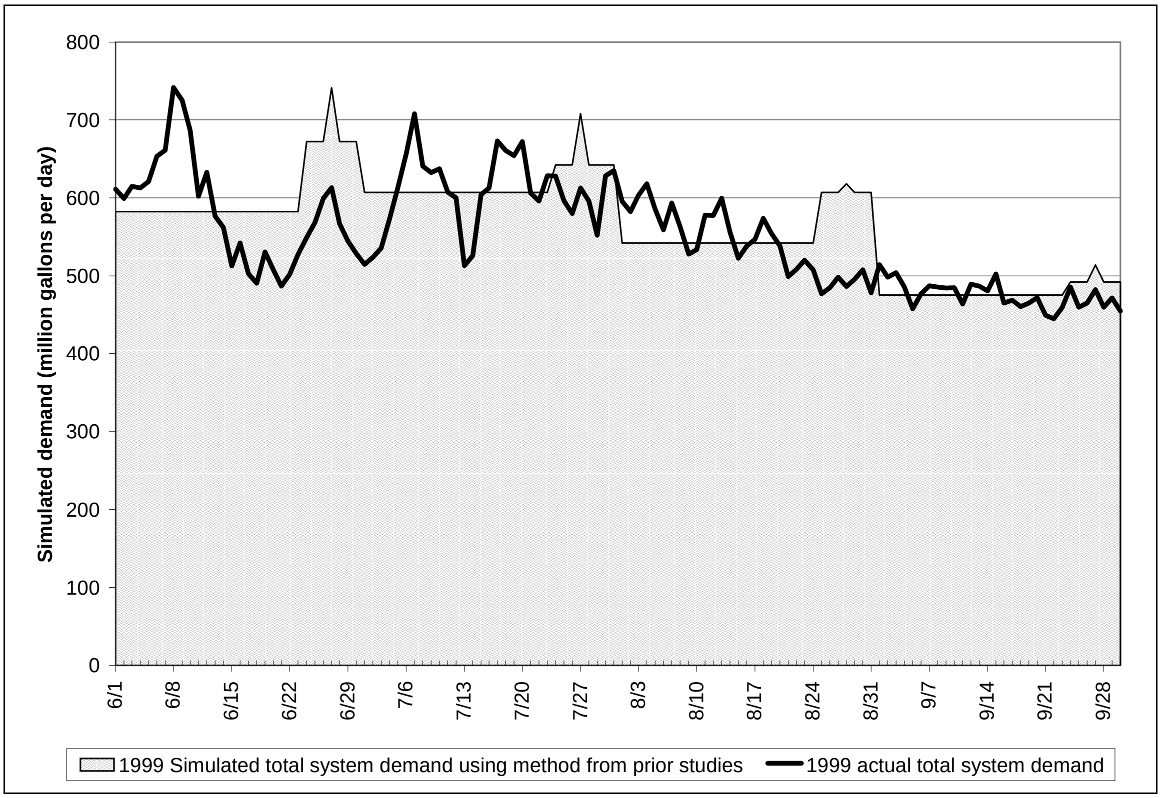

Figure 3-2: Example of simulated demand pattern as used in prior studies as compared to actual system demand

In Potomac system operations, releases are made to meet demands that fluctuate on a daily basis. CO-OP system demands are quite variable. For example, system demands dropped from 757 mgd on June 8, 1999 to 523 mgd one week later on June 15, 1999, a reduction of 234 mgd or 31 percent (Figure 3-2). In order to best simulate Potomac operations (and model the inefficiency of a Jennings Randolph release), an algorithm was developed so that future annual demands can be disaggregated to a demand that varies on a daily basis.

3.4.2 Developing the dataset of daily variable demands

As noted previously, the period of concern for the Potomac is from July 1st through October 31st. This 120-day period is when historical Potomac River flow has the potential for being less than the Potomac demands and environmental flow recommendations. Water supply demands for the July 1st through October 31st period are higher than the annual average demand for each utility and for the CO-OP system. An analysis of CO-OP system 1995 through 1999 production data shows that the average July 1st through October 31st production is in fact 1.03 to 1.14 times the annual average demand as shown in Appendix D under the “Average July 1-October 31 production factor” heading. The average July 1st through October 31st demand was 1.11 times the average annual demand (Appendix D). Daily demands for July 1 through October 31 are thus based on the peak 120-day demand factor of 1.14. The higher number of 1.14 was chosen because it is more conservative and because during hot and dry periods demand is typically higher.

The first step in disaggregating demands was to multiply the 120 day demand factor of 1.14 times the forecast of average annual demand, e.g., 486 * 1.14 = 554.

The second step was to develop an algorithm that converts the 120-day demand into a dataset of daily variable demands. Patterns of recent daily historical demands were used as a basis for developing the algorithm. For each day of the 120-day period, the ratio of a day’s demand to the average 120-day demand for the same year was calculated. These ratios were used as the daily conversion ratios, and were different for each of the 120 days. For example, the ratio of 1998 actual daily demands to average 1998 July 1 through Oct 31 demand was calculated for each day over the July 1 through October 31 period. Applying this ratio to the forecasts of 120-day demand allowed for a disaggregation of demand for each day of the 120-day period.

Daily conversion ratios were calculated for each day using three different years of data as a basis for developing the conversion ratios. (Three different sets of conversion ratios were derived.) These daily ratios for the period July 1 through October 31 were then applied to the forecast of 120-day peak demand in order to develop three different data set of demands that varied by day. The three sets of daily conversion ratios were developed in order to test the sensitivity of the system model results to a particular year’s demand pattern. The model results were relatively insensitive to the particular year’s pattern chosen. The daily pattern based on 1998 demands was thus used as the basis for developing the daily conversion ratios used for disaggregating the forecast of average annual demand for the period July 1st though October 31st.

The third and final step was to develop daily varying demands for the remaining time period, November 1 through June 30. Although no modeled releases from storage would be required during this time period, daily conversion ratios were developed in order to present a forecast of daily demands for the sake of continuity. Monthly demands from November 1 to June 30 were developed based on average monthly demand factors. Average monthly demand factors were based on average system production of each month over the 1995-1999 period, i.e., the last column in Table 3-1. Monthly demands were developed by multiplying the forecast of annual demand by the appropriate monthly factor. Daily demands were developed from the monthly demands using a similar algorithm as used for the period July 1 through October 31. The ratio of actual daily demand to monthly demand was developed for each day for a sample year (1999). Monthly demands were disaggregated based on a given day's ratio of daily to monthly demands.

3.5 Potential trends in production factors

Implicit in the utilization of constant production factors calculated from current production data is the assumption that these factors will remain stationary throughout the forecast period. This assumption was examined for the case of monthly production factors. Figure 3-3 shows the monthly production factors for the period 1974 through 1988, 1990 through 1994, and 1995 through 1999.

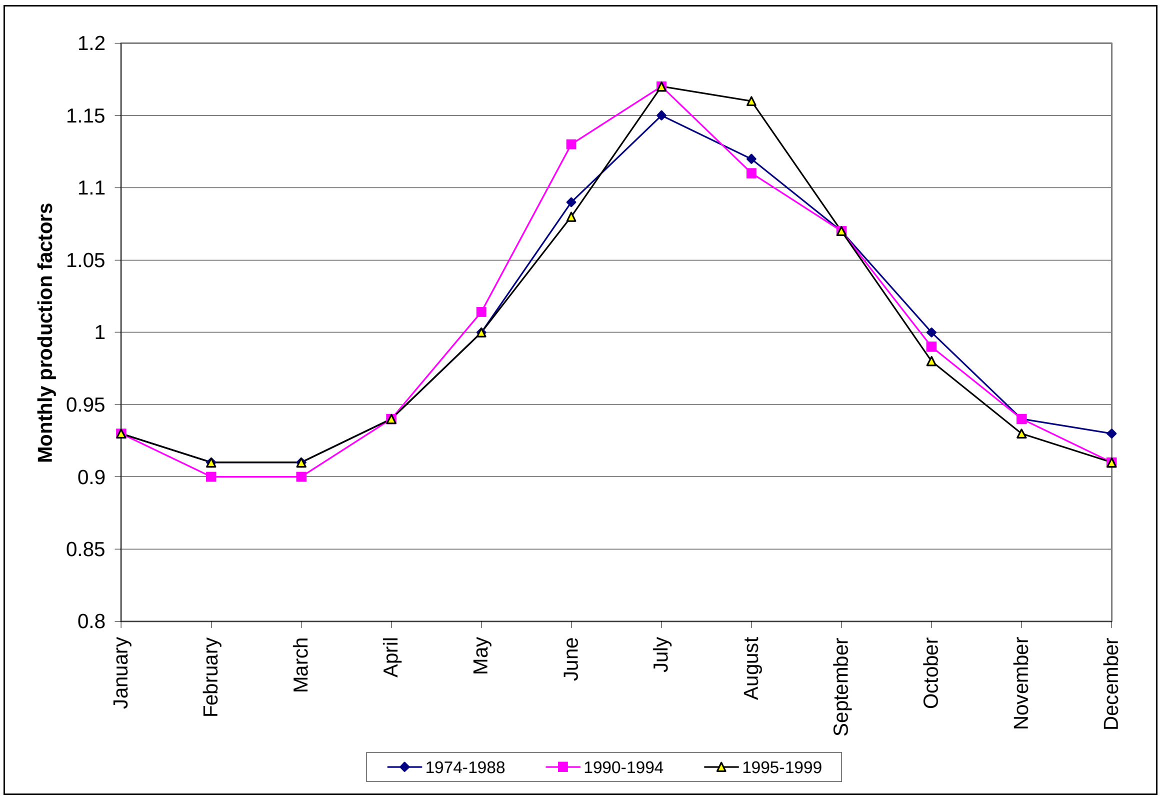

Figure 3-3: System monthly production factors, past and present

Figure 3-3 shows that the system monthly production factors are remarkably consistent over time. The June production factor for 1990-1994 production is slightly higher than it was for 1974-1988. However, The June production factor for 1995-1999 is almost exactly what it was for 1974-1988, indicating that the increase in 1990-1994 June production did not signal the development of a trend. The August production factor for 1995-1999 is higher than it was for both 1974-1988 and for 1990-1994. Future demand studies should continue to monitor whether a trend is developing for higher August production factors.

3.6 Changes in water supply production during 1974-1999 time period.

A review of the recent production data shows the CO-OP suppliers water needs growing during the 1974 through 1999 time period. The CO-OP supplier's annual average production has grown by 28 percent over the last 25 years, from 380.3 mgd in 1974 to 486.9 mgd in 1999.

4 Development of the demand forecast

4.1 Introduction

The following chapter describes the method used to develop the demand forecast, and discusses several factors that can affect demand. The many steps that were used to calculate the forecast are described in detail, including:

- developing the forecast of independent variables (households, employees),
- delineation of utility service area,
- derivation of dwelling unit information,
- calculation of unit use rates,
- estimation of unmetered/unaccounted water use, and
- description of the effects of the *Energy Policy Act of 1992*.

Several factors that can affect demand are described. These include discussion of:

- potential changes in customer demand,
- water use restrictions, and
- potential climate change.

4.2 Method

The estimate of future demands is based on a grouping of all user categories into three types of water uses, namely single family household use, multi-family (apartment) water use, and employee water use. Projections of numbers of households and employees were based on the Metropolitan Washington Council of Governments (MWCOG) Round 6.1 Cooperative Forecast and on a delineation of current and future utility service areas. Information on the number of single family and multi-family homes was obtained for each jurisdiction from local planning agencies. This information was used to separate the MWCOG household forecasts into single family and multi-family units. Coefficients or "unit use factors" were developed for each jurisdiction in the WMA to describe average daily water use by each type of water user. Unit use factors were determined via surveys of individual utility water use. Per household water use was assumed to be lower in the future than it is today as a result of the *Energy Policy Act of 1992.* Demand forecasts were computed by multiplying the number of units for each type of water user by the appropriate unit use rate. Future water demands are calculated for 10 wholesale and retail suppliers with 18 distinct service areas.

4.3 MWCOG cooperative population forecast

Estimates of population, households, and employment to the year 2020 are based on the MWCOG Round 6.1 Cooperative Forecast (Desjardin et al., 1999). These forecasts were developed through a cooperative process involving the Council of Governments, its member jurisdictions, the Baltimore region, 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 6.1, was completed in January of 1999 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 demands at the TAZ level by service area.

MWCOG forecasts were produced for intermediate and high growth scenarios reflecting the range of uncertainty about long-range market and development trends. The range of scenarios was analyzed to determine the sensitivity of the demands to high forecasts of future demands.

4.4 Delineation of utility service area

Household and employment forecasts are associated with each TAZ, which are then aggregated within the service area boundaries of each water supplier. Each utility was contacted to help delineate current and future (2020) service areas. The current service area for the Washington Metropolitan Area is shown in Figure 4-1. The TAZ's for 2000 and for 2020 are shown in Appendices F through I.

4.5 Dwelling unit ratios

Information on the number of single family and multi-family (apartment) homes was obtained for each jurisdiction from local planning agencies. This information was 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. The ratios were compiled using information from the District of Columbia Department of Planning, Arlington County Department of Community Planning, Housing and Development, Fairfax County Planning Department, the City of Alexandria Department of Planning and Zoning, the Loudoun County Department of Planning, The Prince William County Planning Department OIT/GIS, the Montgomery and Prince George's offices of the Maryland National Capital Park and Planning Commission, the City of Rockville Community Planning and Development Services, and the Fairfax County Planning Department.

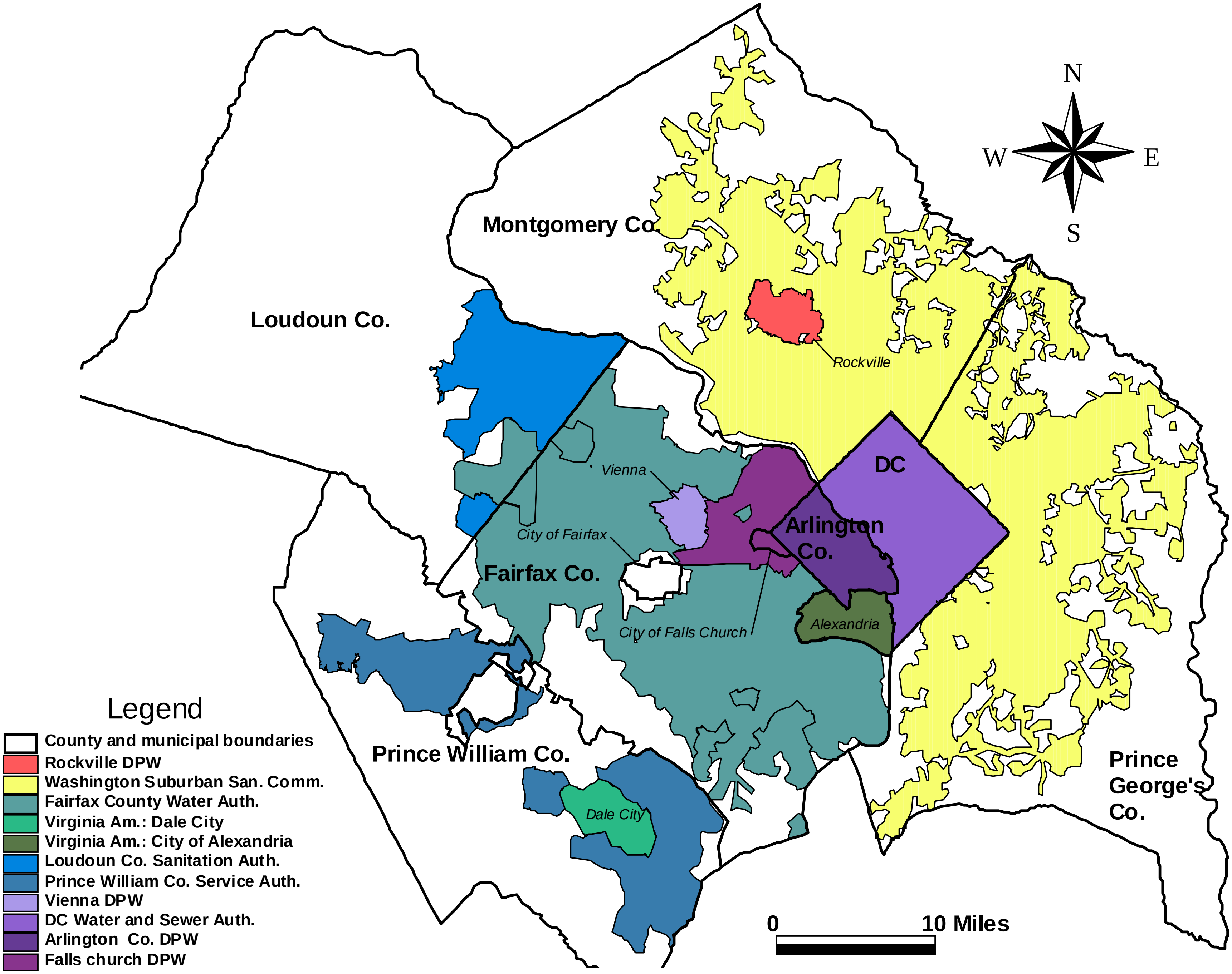

Figure 4-1: Water supplier service areas in the Washington metropolitan area, year 2000

Table 4-1: Dwelling unit ratios by service area

Jurisdiction	Dwelling Unit Ratios [a]					
	1999	2000	2005	2010	2015	2020
Arlington County	0.68	0.67	0.61	0.57	0.54	0.51
District of Columbia	0.71	0.71	0.71	0.71	0.71	0.71
City of Alexandria	0.45	0.45	0.43	0.41	0.40	0.39
City of Rockville	2.40	2.37	2.28	2.20	2.13	2.08
Falls Church	1.60	1.60	1.60	1.60	1.60	1.60
Fairfax County [b]	3.18	3.19	3.21	3.24	3.27	3.29
Montgomery County [c]	2.17	2.17	2.13	2.11	2.08	2.07
Prince George's County	1.86	1.87	1.95	2.02	2.09	2.14
Loudoun County [d]	4.98	4.63	3.74	3.37	3.17	3.06
Prince William County [e]	4.39	4.15	3.37	2.92	2.64	2.47
Dale City [e]	10.93	10.93	10.56	10.22	9.92	9.64

Notes: [a] Ratio of single family to multi family households (townhouses included with single family).
[b] Ratio excludes Fairfax City planning district households.
[c] Ratio excludes Rockville, Bennet, Patuxent, Martinsburg, and Poolesville planning districts.
[d] Ratio includes Dulles South, Dulles North Toll Road, Eastern Loudoun, and Dulles North planning areas.
[e] Ratio calculated for PWCSA service area, as delineated by TAZ (Prince William Co. Planning Department OIT/GIS).

For some jurisdictions, the water supply distribution area boundaries do not correspond exactly with the political jurisdiction boundaries. 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.

The service area for the Falls Church Department of Utilities overlaps three jurisdicational boundaries: the City of Falls Church, the Town of Vienna, and portions of Fairfax County. The dwelling unit ratio for the Falls Church service area was therefore determined from water billing information of the number of single family units served and from the MWCOG Round 6.1 forecast of the total households in that service area. The number of household units in the Reagan National Airport, Dulles International Airport, and Lorton service areas was negligable and the dwelling unit ratio was assumed to be zero. The dwelling unit ratios for Pentagon, Arlington Cemetery, and Fort Myer service areas were assumed to be the same as that of Arlington County. The dwelling unit ratios for the Town of Herndon and Fort Belvoir service areas were assumed to be the same as that of Fairfax County.

Unit use factors were applied to the MWCOG household forecasts to develop estimates of single family and multi-family dwellings. Table 4-2 summarizes the estimated current and future households, population and employees for the CO-OP service area. Appendix E shows a more detailed breakdown of households, population, and employment estimates for each utility service area.

Table 4-2: Forecast of households, population, and employees for the CO-OP service area

	Current 2000 estimates	Forecast for year 2020	Percent increase 2000 to 2020
Households	1,409,889	1,784,705	26.6
Single family	881,441	1,121,773	27.3
Multi-family	528,448	662,933	25.4
Employees	2,440,934	3,174,935	30.1
Population	3,673,603	4,560,838	24.2

4.6 Calculation of unit use factors

The long term water demand forecasting model uses numbers of single family households, multi-family households and employees as a basis for forecasting future average annual demand. This level of disaggregation requires estimates of average daily water consumption per single and multi-family households and per employee for each service area. These unit use factors are displayed in Table 4-3.

Table 4-3: Year 2000 unit use factors by service area

Service area	Single family unit use, gallons per household per day	Multi-family unit use, gallons per household per day	Employee unit use, gallons per employee per day
FCWA - Dulles	NA	NA	47.9
FCWA - Ft. Belvoir	218.6	191.8	50.1
FCWA - Herndon	218.6	191.8	23.4
FCWA - Lorton	NA	NA	120.9
FCWA - Loudoun Co. Sanitation Authority	275.4	158.8	29.8
FCWA - Prince William Co. Service Authority	264.4	191.8	62.7
FCWA - Retail service area	218.6	191.8	45.8
FCWA -Virginia American - Alexandria	204.4	180.5	45.8
FCWA -Virginia American - Dale City	199.9	191.8	88.2
Aqueduct - Arlington Co. DPW	185.0	150.3	48.9
Aqueduct - Falls Church DPU	185.0	150.3	45.7
Aqueduct - Falls Church - Vienna DPW	185.0	150.3	45.7
Aqueduct - WASA - District of Columbia	304.4	304.4	43.8
Aqueduct - WASA - National Airport	NA	NA	47.9
Aqueduct - WASA - Pentagon, Arlington Cemetery, and Fort Myer	185.0	150.3	50.1
WSSC: Montgomery County[a]	181.8	183.8	44.2
WSSC: Prince George's County[a]	181.8	183.8	44.2
City of Rockville	185.0	150.3	51.1

Notes: [a] The unit use factors for the WSSC are not consistent with the number WSSC is using in planning and seems incongruent because the multi-family factor is higher than the single family factor. The numbers WSSC is using for planning are as follows: single family: 197; multi-family: 173; and employee: 42 (in consistent units with Table 4-3). Using the WSSC factors, the total demand for 2020 is virtually identical to that demand calculated using the factors listed in Table 4-3.

A survey of each water utility was conducted to determine the unit use rates specific to each jurisdiction. Each utility was asked to describe its water use by customer service category for the most recent year of available water use data, usually from 1998. Typical customer service categories included single family residences, multi-family residences, and commercial accounts. The amount of water consumed for each customer service category was divided by the number of single family, multi-family households, or employees in the service area. The resulting coefficients describe the unit use for each category of water use. The calculation of unit use factors is detailed in Appendix J for each service area. Unaccounted/unmetered water was determined as based on the difference between water produced (or bought at the wholesale level) and that actually billed to individual customer accounts and is shown in Appendix J for each supplier.

4.7 Effects of *Energy Policy Act of 1992*

The unit use factors, in part, drive the water demand forecast model. These unit use factors were not assumed to be stationary throughout the forecast period. Instead, these factors were reduced over time to account for the growing use of low water using fixtures as a result of the *Energy Policy Act of 1992*. Table 4-4 shows the estimate of changing per household water use in the WMA.

Table 4-4: Estimated effects of *Energy Policy Act of 1992* on WMA household water use

	1990	2000	2010	2020
Per household toilet use, gallons	45	40	33	28
Per household shower use, gallons	33	31	29	28
Total difference from 2000 conditions, gallons	7	0.0	-9	-16

Table 4-4 shows that average per household water use in 2020 in the WMA is expected to be approximately16 gallons per day less than it is in the year 2000 due to increased installation of low flush toilets and low flow showerheads. Appendix K gives a detailed explanation of how the effects of the *Energy Policy Act of 1992* on WMA water use were estimated.

4.8 Recognition of potential changes in customer demand

The anticipated effects of the increasing use of low-flow toilets and showers in the Washington metropolitan area are incorporated into the estimate of future demands as discussed in Section 4.7. Additional ongoing programs to promote efficient use of water are in place at the WMA CO-OP utilities. These programs are generally called conservation programs and examples of the water utilities' conservation efforts include helpful information and "tips" prominently displayed on utility Internet web sites and on messages in bill inserts. Educational outreach programs such as exhibits at community events, speakers' programs, press releases, and distribution of publications have been emphasized. Also, inclining rate structures, with higher water rates applying to higher customer demands, have been in place throughout much of the WMA. The impacts of the water utilities' programs are reflected in current levels of per capita water consumption.

The MWCOG's Board of Directors has resolved to implement a year-round plan building on regional conservation efforts, emphasizing wise water use and conservation (MWCOG Board Task Force on Regional Water Supply Issues, 2000) through an annual public information program. The conservation effects and customer demand impacts of this program are still unknown. Future water demand studies will continue to incorporate the effects of ongoing conservation and demand management policy efforts into estimates of per capita water use. The COG plan also outlines a regionally coordinated public response plan under which voluntary and mandatory water restrictions would be implemented at various trigger levels. Water use restrictions were assumed to reduce customer demand in the current study as outlined in Section 4-9.

To quantify additional reduction in water demand beyond that of the suite of water conservation programs already in place, a detailed assessment would need to be conducted to determine potential changes in demand and the cost and benefit of these changes. Given the scope of this WMA study, an accurate assessment of additional conservation potential in this region would be difficult, if not impossible, to perform. Instead of attempting to quantify conservation potential, a sensitivity analysis is included to show how the system of resources responds to different realizations of future demand under a repeat of historical streamflow conditions. Section 6-12 provides a sensitivity analysis showing how the water supply system is affected by a range of demands that are both higher and lower than the most likely forecast of future demand.

4.9 Effects of water use restrictions

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

In actual operations, water utility managers would not deplete all reservoir storage, but instead would rely on emergency restrictions to preserve emergency reservoir storage during a severe drought.

Recently, 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 demands in the daily timestep simulation model. Instead, when either Jennings Randolph or Little Seneca storage drops below 25 percent full, mandatory restrictions were implemented in model runs. Based on WMA experience during the drought of 1999, voluntary restrictions were assumed to have an associated reduction in demand of 10 percent. Mandatory restrictions were assumed to lower system demands to average wintertime (January) base demand levels in model runs.

4.10 Potential effects of climate change on future demands and resources

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

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

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

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

4.10.1 Potential climate change effects on demand

Results from the five models of predicted temperature and precipitation were converted to potential evapotranspiration and effective precipitation, respectively. The excess of potential evapotranspiration over effective precipitation defines the moisture deficit which has been shown to be a useful explanatory variable for seasonal water use in residential areas (Linaweaver 1965, cited in Boland, 1999). IWR-MAIN, a detailed demand forecasting model, was used to predict demands in part because it incorporates moisture deficit as a predictor of residential water use. Base year (1990) water use data was collected for all of the Washington area jurisdictions. IWR-MAIN was used to estimate base year water use as a function of moisture deficit and literature values for specific end user water use rates. This model verification produced results within 5 percent of reported water use. Based on the successful verification, IWR-MAIN was used to prepare water use forecasts for each jurisdiction and for each climate change scenario.

The results suggest that compared to the stationary climate assumption, there is a possibility of a substantial increase in year 2030 summer water use as a result of climate change under assumptions of several of the GCMs. The UKMO model showed the greatest change: a 19 percent increase in the July, August, and September demands. Assuming a linear trend from 1990 to 2030 for the climate change study implies a 9.5 percent change from 2000 to 2020 demands for the period of the current study. Therefore, the maximum predicted increase in 2020 demands of 9.5 percent in July through September demands was adopted as a potential climate change scenario effect on demands as discussed in Section 6-15.

4.10.2 Potential climate change effects on water resources

The climatic data derived from the selected GCM model runs (precipitation and temperature) was translated into water supply source availability scenarios (river flow and reservoir inflow) through the application of water balance models for each major water supply source in the WMA system. The Thornthwaite and Mather (1955) water balance model was selected for this purpose, because it incorporates as inputs precipitation and temperature to generate watershed runoff as annual hydrographs of average monthly values. A source of uncertainty is introduced in transforming precipitation and temperature GCM outputs into values of watershed runoff.

A further source of uncertainty in this method was that the GCM outputs were in terms of *average* monthly precipitation and temperature. The outputs could only be used to generate projections on similar statistics, that is, to project long term *average* values rather than trends or extremes. Precisely what is needed for the current study is a prediction of how extreme event (drought) flows might be affected by climate change.

There are numerous and substantial uncertainties associated with anticipated climate change, not least of which is the lack of any clear climate result for this region from the five different GCM model runs; therefore, no potential climate change impacts were incorporated in the analysis of resources for the present study. However, analysis was conducted to determine the sensitivity of the Potomac reservoir system to changes in streamflow resources and demands in Section 6-14.

5 Forecasts of future water demands

5.1 Introduction

Results of the water demand forecast are presented in this chapter. Forecasts of water demands for each service area by supplier are presented. A section comparing the forecasts developed in this study to earlier forecasts follows. Past years' demands were estimated and compared with actual demands in order to validate the method used to estimate demand. This chapter concludes with a short description of some sources of uncertainties that may affect the likelihood of this study's forecast being realized.

5.2 Most likely forecasts of water demands

Annual water demands are forecast to increase for most Washington metropolitan area suppliers. These results are summarized in Table 5-1.

Table 5-1: Forecast of average annual water demands for the WMA

Service area	2000	2005	2010	2015	2020
FCWA – Dulles	0.8	0.9	1.0	1.1	1.1
FCWA - Ft. Belvoir	1.9	2.3	2.7	3.0	3.2
FCWA – Herndon	2.3	2.5	2.7	2.9	3.0
FCWA – Lorton	0.1	0.01	0.03	0.03	0.03
FCWA - Loudoun Co. Sanitation Authority [a]	4.8	7.1	10.6	13.9	17.2
FCWA - Prince William Co. Service Authority [a]	12.4	15.9	19.1	22.2	24.0
FCWA - City of Falls Church	0.1	0.1	0.1	0.1	0.1
FCWA - Town of Vienna	0.8	0.8	0.8	0.8	0.8
FCWA - City of Fairfax	0.5	0.5	0.5	0.5	0.5
FCWA - Retail service area	89.9	95.9	101.1	105.8	109.5
FCWA -Virginia American – Alexandria	16.8	17.2	17.5	17.7	17.8
FCWA -Virginia American – Dale City	4.7	4.7	4.8	4.8	4.7
Total FCWA	**135.0**	**147.8**	**160.8**	**172.8**	**182.0**
Aqueduct - Arlington Co. DPW	27.9	28.5	30.2	31.5	32.8
Aqueduct - Falls Church DPU and Vienna DPW [b]	16.9	17.7	18.9	18.8	19.2
Aqueduct - WASA - District of Columbia	130.4	131.3	136.1	141.2	144.9
Aqueduct - WASA - National Airport	0.5	0.5	0.5	0.5	0.5
Aqueduct - WASA - Pentagon, Arl. Cemetery, Fort Myer	1.7	1.8	1.8	1.8	1.8
Total Aqueduct	**177.5**	**179.9**	**187.5**	**193.8**	**199.2**
WSSC: Montgomery County	88.8	93.8	98.4	102.5	104.9
WSSC: Prince George's County	78.7	82.4	85.8	89.2	93.1
Total WSSC	**167.5**	**176.2**	**184.2**	**191.7**	**197.9**
Total WMA CO-OP service area	**480.0**	**503.9**	**532.5**	**558.3**	**579.1**
Others: City of Rockville	6.6	6.9	7.1	7.2	7.2

Notes: [a] Indicates water purchased from FCWA and does not include water purchased from other sources.
[b] Indicates water purchased from the Aqueduct and does not include water purchased from other sources.

Table 5-1 shows that the overall CO-OP average annual demand is expected to increase by 99.1 mgd. Of this total, FCWA water demands are forecast to increase by 47 mgd, the Aqueduct by 21.7 mgd, and WSSC by 30.4 mgd. A complete listing of demands by water class for each service area is given in Appendix L.

Growths in annual average demands from 2000 to 2020 by supplier service area and water use class are shown in Table 5-2. Table 5-2 shows the projected increase in water use for each jurisdiction for each category of water user, single family, multi-family, and employee.

Table 5-2: Growth in demand by water use category from 2000 to 2020

Service area	Single family	Multi-family	employee
FCWA - Dulles	0.0	0.0	0.5
FCWA - Ft. Belvoir	0.3	0.1	0.7
FCWA - Herndon	0.5	0.1	0.1
FCWA - Lorton	0.0	0.0	-0.1
FCWA - Loudoun Co. Sanitation Authority	10.2	2.2	1.6
FCWA - Prince William Co. Service Authority	5.1	2.8	3.0
FCWA - Retail service area	7.1	1.4	5.8
FCWA -Virginia American - Alexandria	-0.3	0.5	0.8
FCWA -Virginia American - Dale City	-0.1	0.0	0.1
Total FCWA	22.8	7.1	12.6
Aqueduct - Arlington Co. DPW	-0.7	1.1	3.6
Aqueduct - Falls Church DPU and Vienna DPW [b]	0.5	0.2	1.3
Aqueduct - WASA - District of Columbia	2.7	3.8	4.3
Aqueduct - WASA - National Airport	0	0.0	0.0
Aqueduct - WASA - Pentagon, Arlington cemetary, Fort Myer	0	0.0	0.0
Total Aqueduct	2.5	5.1	9.2
WSSC: Montgomery County	4.6	3.1	5.5
WSSC: Prince George's County	5.8	0.5	5.5
Total WSSC	10.3	3.6	11.0
Total WMA CO-OP service area	35.6	15.8	32.8
Others: City of Rockville	-0.1	0.1	0.5

Note: Table 5-2 does not include unaccounted/unmetered water use

Table 5-2 shows that most of FCWA's retail and wholesale water use growth is projected to be in the single family residential category. 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 roughly split between single family and employee use. Overall, the main increase in CO-OP utility future water use is projected to be roughly split between single family and employee water use. Some jurisdictions show a slightly lower water use in the single family category, due to relatively static population growth combined with declining unit use rates.

Forecasted annual average demands are disaggregated into peak 1-day, peak 7-day, monthly average, and peak 120-day demands utilizing production factors discussed in Chapter 3. A complete listing of the disaggregated forecast of demands is located in

Appendix M for the Aqueduct, Appendix N for FCWA, and Appendix O for WSSC. The CO-OP system total forecast of disaggregated demands is shown in Appendix P.

5.3 High growth scenario estimate of demands

High estimates of future growth were used as an alternative basis on which to predict future demand. MWCOG demographic forecasts are produced for high, intermediate, and low growth scenarios reflecting the range of uncertainty about long-range market and development trends. The MWCOG high growth demographic scenario was used as the basis to determine the sensitivity of the demands to potentially higher realizations of demographic growth. A high growth scenario results in an increase of annual water use from 480 mgd to 606 mgd, an increase of 126 mgd (26 percent).

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 two earlier studies of Washington area demands; the *1995 Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Mullusky et. al, 1996) and the *Metropolitan Washington Area Water Supply Study* completed in 1983 by the Army Corps of Engineers (U.S. Army Corps of Engineers, 1983) as shown in Figure 5-1. Both earlier studies use the same basic method as this study, but earlier demographic data.

Figure 5-1 shows that the current CO-OP forecast of annual average demand for 2020 is 131 mgd below the level forecast by the 1983 study and 44 mgd below the level forecast by the 1995 study. The lower forecast in this study is due to several factors, including updated demographic forecasts, updated unit use factors, and incorporation of the effects of the *Energy Policy Act of 1992*.

A log linear regression was performed to extrapolate the forecast of 2020 demand to a forecast of demand for 2040. This method assumes that dwelling unit ratios remain constant and assumes a continued lowering trend in unit use rates as a result of the *Energy Policy Act of 1992*. The demand extrapolation allowed 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 2020 horizon is a rough approximation.

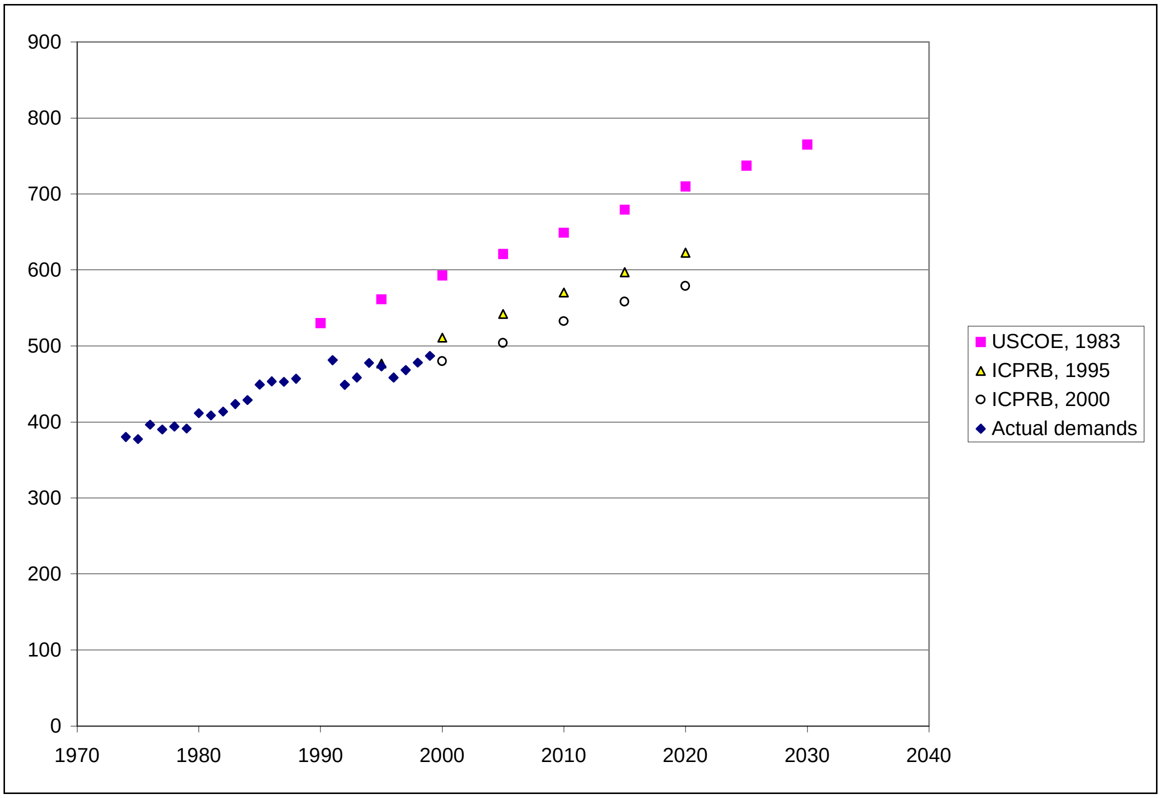

Figure 5-1: Comparison with forecasts from earlier studies

5.5 Demand model validation

Past years' demands were estimated and compared with actual historical demands in an effort to validate the method used to forecast demand. MWCOG estimates of households and employees were available for both 1990 and 1995. These estimates were disaggregated by utility service area using TAZ delineations. Estimates of unit use were developed for 1990 and 1995 households and employees. Unit use rates were based on the survey of recent water use and were adjusted to account for changing water use patterns due to the effects of the *Energy Policy Act of 1992* per Table 4-4. Ratios of single family to multi-family households in 1990 and 1995 were used to estimate numbers of each population for each year. Current rates of unaccounted for water were assumed to have been the same in 1990 and 1995 as they were calculated for 2000. Overall water use for 1990 and 1995 was calculated using the same method as developed for the current study for each jurisdiction. Figure 5-2 shows the calculated and actual water use rates for the CO-OP utilities for the last decade. Figures 5-3, 5-4, and 5-5 show the calculated and actual water use for FCWA, WSSC, and the Aqueduct.

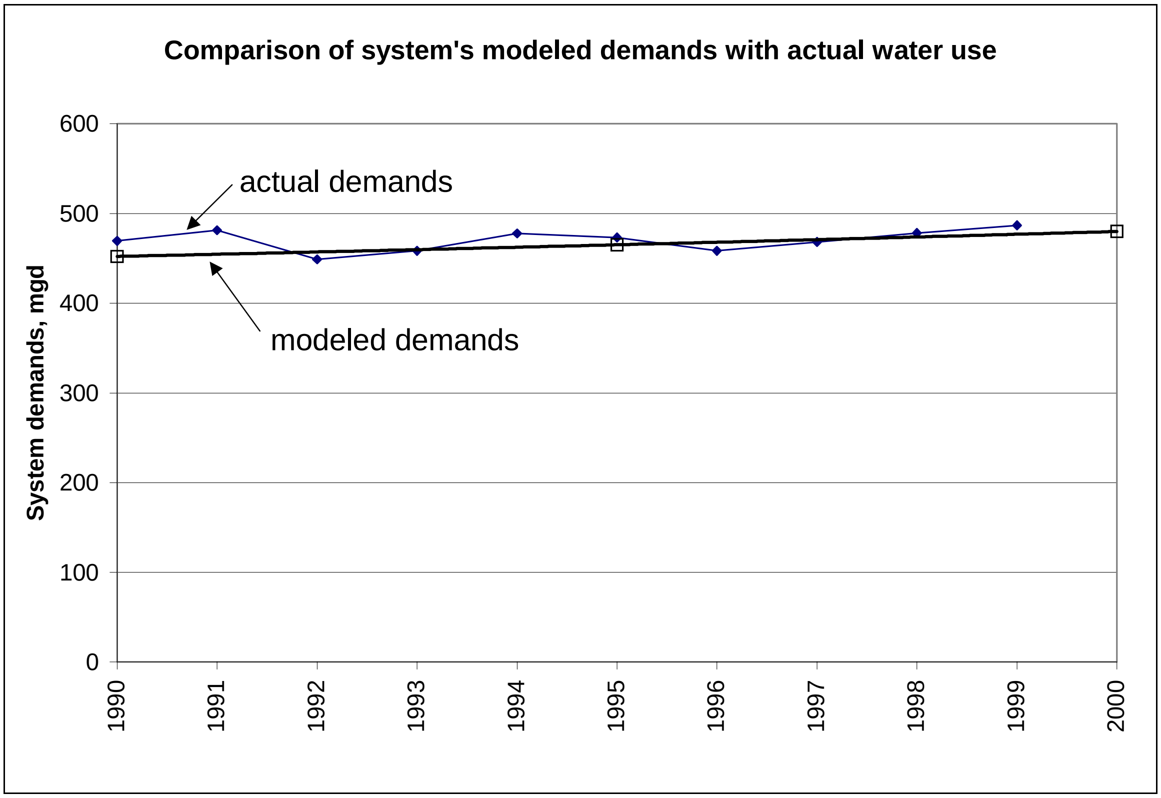

Figure 5-2: Calculated (modeled) and actual demands for the CO-OP utilities

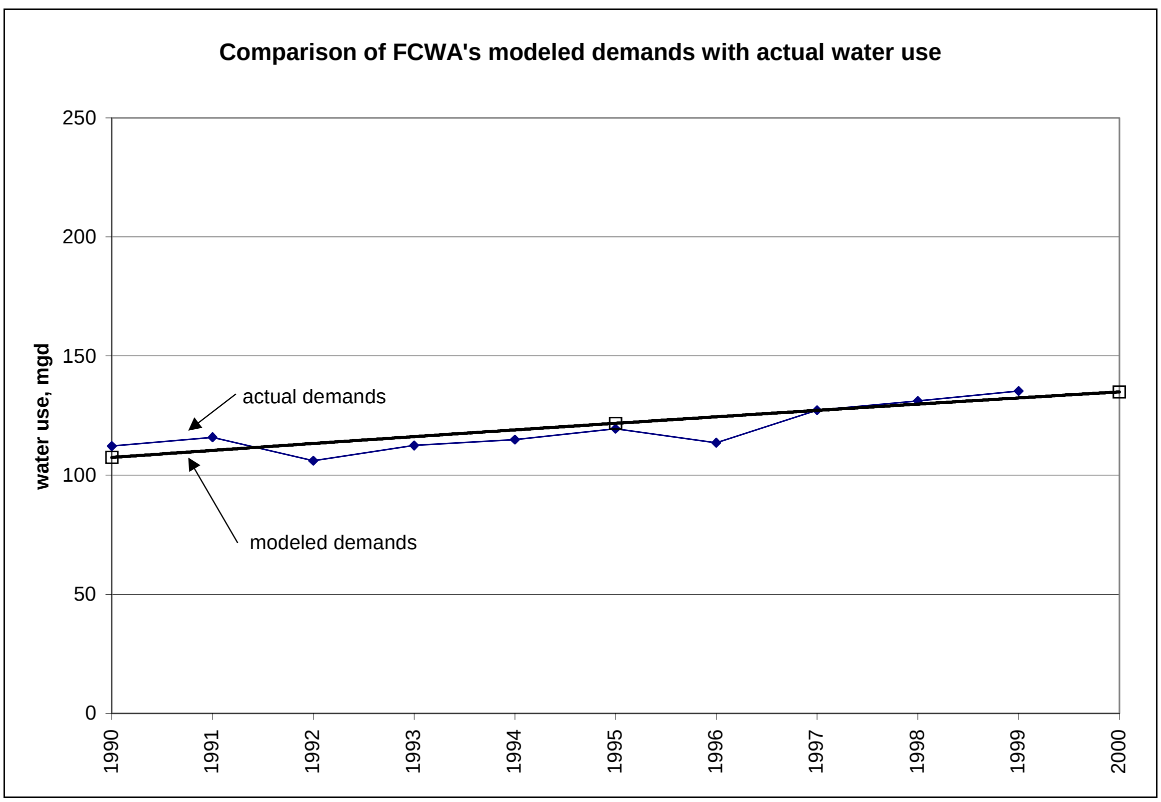

Figure 5-3: Calculated (modeled) and actual demands for FCWA

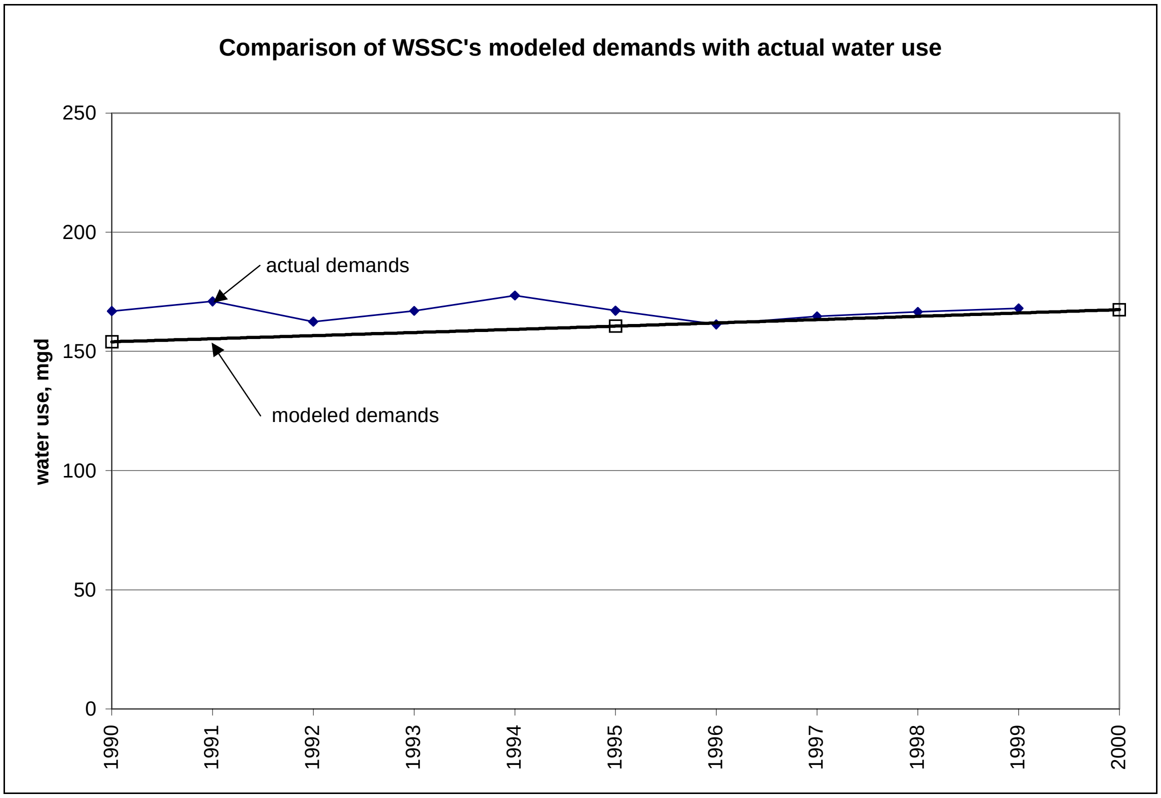

Figure 5-4: Calculated (modeled) and actual demands for WSSC

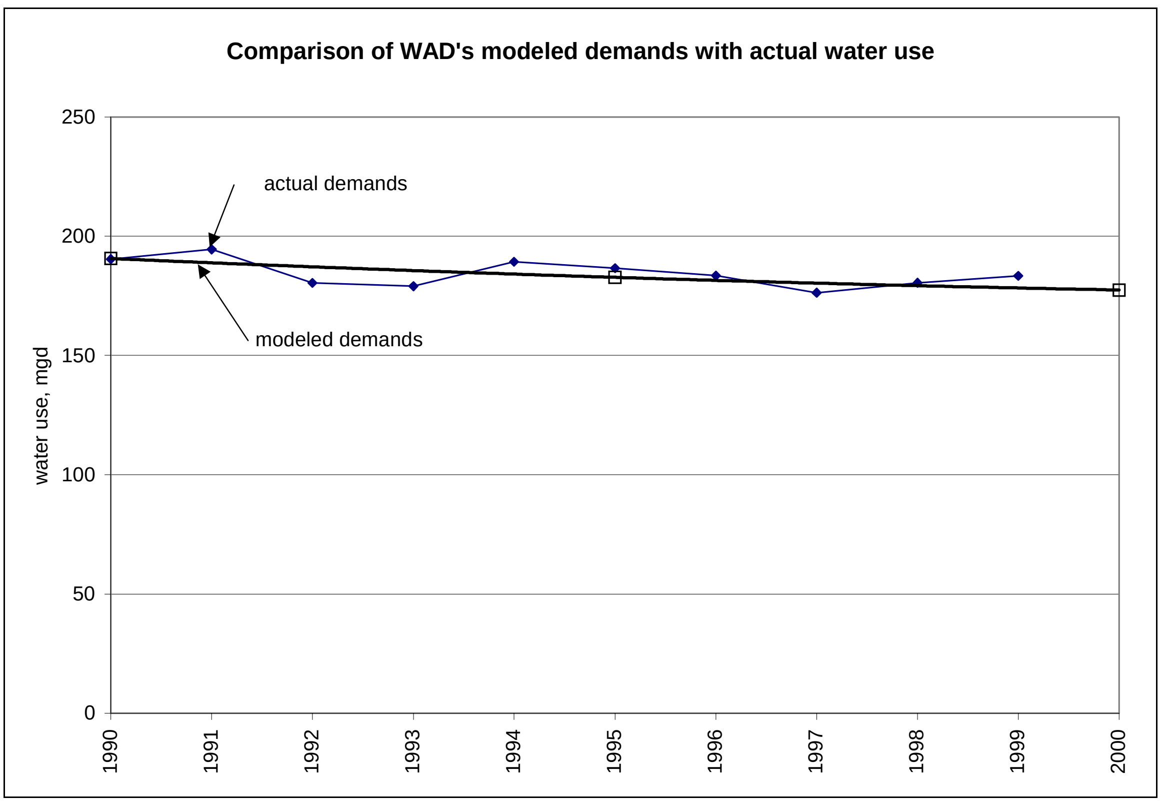

Figure 5-5: Calculated (modeled) and actual demands for the Aqueduct

Figures 5-2 through 5-5 show that the calculated water use well matches actual historical water use, increasing confidence in the method used to estimate future demand. Figure 5-4 shows that the method slightly under-predicted water consumption for WSSC in 1990 through 1995. WSSC had a higher unit use in 1990 and 1995 than was predicted. WSSC personnel indicate that this was probably due to two factors: 1) a change in the billing structure in the early 1990's, and 2) rate increases of 9.9 percent, 9.0 percent 13.6 percent, and 9.2 percent in 1991, 1992, 1993, and 1994 respectively that caused a lowering over time in its average per capita water use.

5.6 Uncertainties in water demand forecasting

Several uncertainties in forecasts of future water demands affect their likelihood of realization. These uncertainties include:

- Accuracy of demographic projections. These uncertainties range from local to national economic and demographic factors from which estimates of households and employment levels are derived.

- Unforseen political or economic pressures. Economic downturns could affect regional growth patterns.

- Potential climate change. Long term variation in climate may affect demands and supplies in ways that are difficult to forecast.

6 Resource analysis and results

6.1 Introduction

The objective of this chapter is to present an assessment of the existing water system's ability to meet future demands. This chapter describes the system model that was developed for the resource assessment portion of the study as well as current CO-OP water supply operations. Several factors that can affect future resources were investigated and are presented in this chapter, including:

- Jennings Randolph release efficiency,
- the effects of siltation on reservoir storage over time,
- increasing return flows from wastewater treatment plants upstream of the Potomac water supply intakes and Occoquan Reservoir,
- the current recommended environmental flow rate for Little Falls,
- water quality releases from Jennings Randolph water quality storage,
- the potential effects of climate change on resources, and
- upstream consumptive water demands.

Results of the resource analysis are presented in terms of how future demands affect modeled system reservoir storage under an assumed re-occurrence of historical flows. Results are also presented in terms of how future demands would affect the magnitude, duration and frequency of historical Potomac River low flow throughout the 67-year period for which flow data have been developed. Finally, two sensitivity analyses are presented. The first analysis shows how robust the system is to different forecasts of future demands for the year 2020. The second analysis describes how much the resources (river flows and reservoir inflows) would have to change before the system failed.

6.2 Model description

A deterministic system simulation model was developed that incorporates the daily operating rules of the system of reservoirs for the WMA, fluctuating daily and seasonal demands, and 67 years of continuous historical flows. The model is called the Potomac River and Reservoir System Model, PRRSM. PRRSM 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. PRRSM also models the Occoquan and Patuxent reservoirs, which provide about 25 percent of the total water supplied in the WMA.

The modeling algorithm in PRRSM can be compared to an accounting procedure, tracking reservoir inflows and releases and Potomac flows in order to calculate daily reservoir storage and river flow throughout the historical record. PRRSM can thus be used to determine how the current system of reservoirs and the Potomac River would respond to current or future demands given the current reservoir operating procedures and the historical record of streamflow.

Inputs to PRRSM include a choice of forecast year (2000 to 2040) and a choice between most likely and high growth estimates. PRRSM provides outputs of:

- daily reservoir volumes for Jennings Randolph, Little Seneca, Patuxent, and Occoquan reservoirs,
- Potomac River flow upstream and downstream of the water supply intakes,
- Potomac "natural" flow (that flow unaffected by upstream human activities such as reservoir regulation, consumptive use, wastewater return flows, or water supply withdrawals),
- overall efficiency of the Jennings Randolph and Seneca releases,
- magnitude and frequency of low flows, and
- number of days of releases.

PRRSM is run in a continuous mode through the 67 years of deterministic historical reservoir inflow and Potomac River flow records on a daily time step. 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 through the fall and winter of 1930-1931.

Water supply demands in PRRSM are modeled to incorporate seasonal and daily variability in demand as described in Chapter 3. PRRSM simulates CO-OP system reservoir operations as described in Sections 6-3. PRRSM models the Jennings Randolph release efficiency (Section 6-4), reservoir siltation over time (Section 6-5), the effects of increased upstream wastewater return flows (Section 6-6), current environmental flow recommendations (Section 6-7), current water quality releases from Jennings Randolph (Section 6-8), and upstream consumptive water demands Section 6-9).

6.3 Operations

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

Jennings Randolph and Little Seneca reservoirs are used to augment low flows in the Potomac River. Jennings Randolph and Little Seneca releases are made when predicted demands plus environmental flow requirements are greater than predicted Potomac flow. Because Jennings Randolph Reservoir is some 200 miles upriver, releases must be made approximately nine days in advance to allow for travel time downstream.

The operations procedure for a Jennings Randolph release is to determine how much water, if any, to release from Jennings Randolph Reservoir in order to meet anticipated demands nine days in the future. The Little Seneca Reservoir, less than a day's travel time from metropolitan intakes, is used in conjunction with Randolph so that releases made from the latter can be more conservative. If the Jennings Randolph release is too small (because of lower than expected river flow or higher than expected demands), a release can be made from the smaller, closer reservoir to make up for any temporary shortfalls that become apparent as Jennings Randolph water travels to the intakes. These operations were incorporated into PRSSM.

To determine the Jennings Randolph release in actual operations, streamflow throughout the watershed is monitored. The USGS's real-time flow data are invaluable in obtaining a snapshot of flow conditions and for evaluating flow trends. For example, up to 17 USGS graphs depicting gage readings of Potomac and tributary streamflow were analyzed each day during the drought of 1999. Flow regressions for major tributary flows were developed to estimate streamflow recessions. Forecasts of major tributary flows, based on the tributary flow regressions, were used to develop forecasts of Potomac flow at Washington in 9 days time. Tributary flows and associeated flow regression equations were incorporated into PRRSM so that a flow forecasting algorithm could be established in the model.

6.4 Jennings Randolph and Little Seneca efficiency of operations

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

Figure 6-1 compares the predicted Potomac flow upstream of Little Falls in 9 days time with subsequent actual flow in the Potomac during the low flow conditions of 1966. The predicted flow is based on flow regressions from gages at Hancock, Conococheague, Antietem, Shenandoah, Monocacy, and Little Seneca, using only that information available 9 days prior to the actual flow. Figure 6-1 shows that the predicted flow approximates actual flow albeit imperfectly.

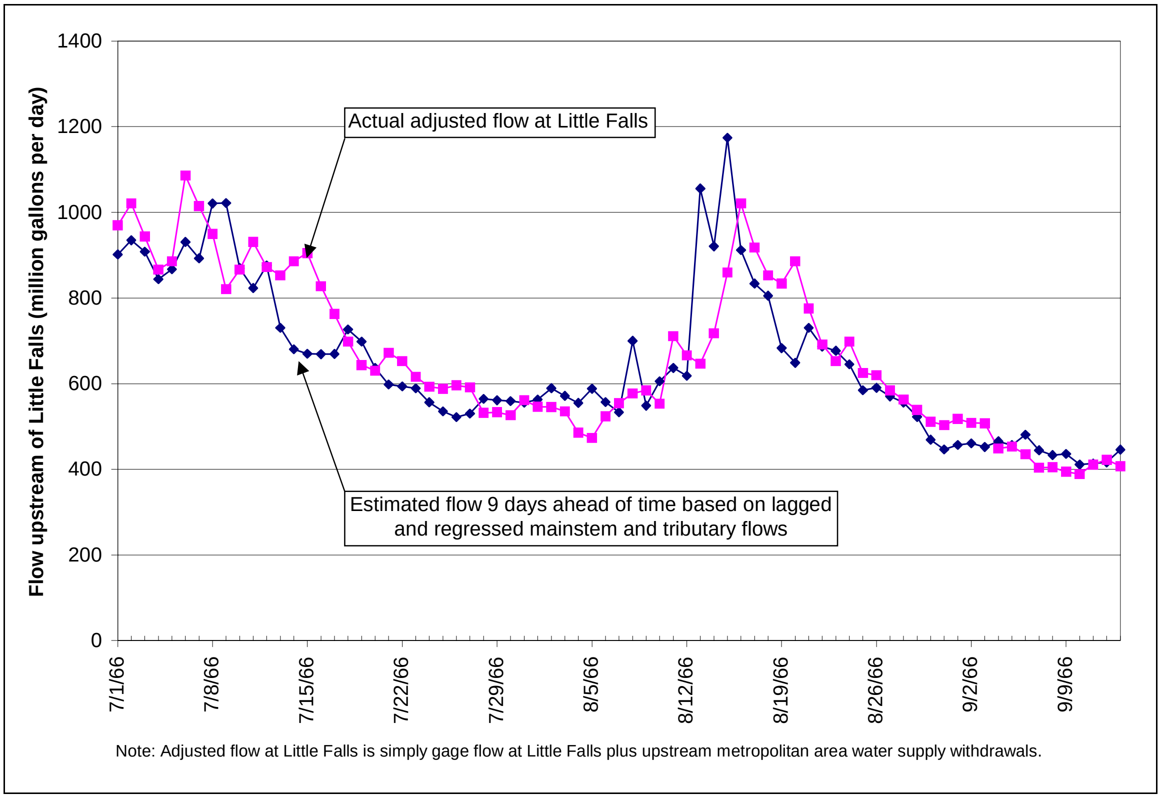

Figure 6-1: Comparison of predicted and actual flows upstream of Little Falls

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 PRRSM calls for an initial day's release of 200 mgd whenever the forecast of demands is greater than the forecast of river flow 9 days hence. The large release is made to quickly get the water to the intakes as a "wave." Subsequent day's releases are at least 100 mgd whenever the forecast of 9-day demands is greater than the forecast of river flow 9 days hence. Little Seneca is assumed in model runs to be 100% efficient.

6.5 Effects of sedimentation on reservoir storage

Reservoir storage was assumed to decrease over time due to the effects of reservoir sedimentation. Table 6-1 shows the current and projected reservoir storage for the system reservoirs. Sedimentation rates were determined using the most recently available bathymetric surveys. Current reservoir storage was compared to original estimates of reservoir storage to determine storage loss over time. ICPRB reports 98-3, 98-4a, 98-5, and 99-3 show the calculations of reservoir sedimentation for the system reservoirs. The changes in reservoir storage were incorporated into the system model as a function of forecast year.

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

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

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 downstream at the original withdrawal point. These return flows were estimated for future years and incorporated into PRRSM as available for future use. The facilities considered for this analysis include WSSC's Seneca WWTP, Loudoun County Sanitation Authority's planned Broad Run WWTP, and the Upper Occoquan Sewage Authority's (UOSA's) WWTP. Table 6-2 shows the current and projected WWTP return flows for these three facilities. The increases in treated wastewater return flow were incorporated into PRRSM as a function of forecast year.

Table 6-2: Current and projected WWTP return flows for the WMA

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

6.7 Environmental flow recommendations

The current environmental flow recommendations for the WMA were used for the resource analysis. The recommendations are based on a 1981 study (MD DNR, 1981). The flow recommendations include a 300 mgd minimum daily flow downstream of Great Falls and a 100 mgd minimum daily flow downstream of Little Falls. During one of the public information meetings for this study (October 29, 1999; Appendix Q), the issue was raised that the environmental flow recommendations might change if the original 1981 study is updated. There are no studies specific to the Potomac since 1981 that indicate other values that could be used, so the 1981 rates were assumed for the demand and resources analysis. The modeling tools developed for this analysis are easily updated for inclusion in a broader scope study to examine the environmental flow issue.

6.8 Jennings Randolph water quality release

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

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

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

Modeling analysis shows that the 120 cfs release can be maintained throughout the historical streamflow record, even in the event of a multi-year drought. Therefore, it was assumed that future water quality releases are simply equal to 120 cfs during a water supply release. This assumption greatly simplifies the programming involved in the simulation model PRSSM.

6.9 Upstream consumptive demands

An examination of cumulative consumptive demand in the Potomac basin was conducted in the *Water Supply Demands 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 utilities.

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).

Potential variation in seasonal water use patterns and in drought year use were quantified in the Basin Study. Seasonal year variation in agricultural irrigation withdrawals and outdoor domestic water use were estimated for the peak use months of June, July and August, and were also adjusted to represent those higher demands that would be expected during hot and dry (drought) years. Commercial, industrial, thermoelectric, mining, and livestock consumptive demands were also estimated and were assumed to be unchanged by drought versus normal year conditions or by seasonal factors.

Total June through August consumptive use in the Potomac basin upstream of the metropolitan water supply intakes for 2000 was estimated to be 129 mgd 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.

Upstream consumptive demand was estimated for the remaining months (i.e., September through May) using the information provided in the Basin Study. Upstream consumptive demand in these months was assumed unchanged by drought versus normal year conditions. Total September through May consumptive use in the Potomac basin upstream of the metropolitan water supply intakes for 2000 was estimated to be 42 mgd, increasing by 4 mgd to 46 mgd in 2020. September through May consumptive use was calculated as the sum of commercial, industrial, thermoelectric, mining, and livestock consumptive uses. Irrigation and domestic consumptive water use were assumed to be zero during the September through May period.

Stream flow resources were modified in the computer simulation model PRRSM to account for present and expected consumptive demands. It was assumed that actual consumptive use in 1929 was zero and that the 1929 historical streamflow record had to be adjusted to represent current and future consumptive use patterns. The 129 mgd consumptive demand was subtracted from 1929 historical flow in June, July and August, and the 42 mgd consumptive demand was subtracted from 1929 historical flow in the remaining September through May months. No adjustment was made to the historical streamflow record for 1997. For years between 1929 and 1997, the historical streamflow record was adjusted by subtracting an amount that varied linearly from 129 mgd in 1929 to zero mgd in 1997 for June through August months, and from 42 mgd in 1929 to zero mgd in 1997 for the remaining months. A further adjustment to streamflow resources was made to account for projected consumptive use. When projected year 2020 demands were modeled, all years of streamflow resources were decreased by an additional 20 mgd in the months of June, July and August and by 4 mgd for the remaining months.

6.10 Results

Although the MWCOG population forecast was for the year 2020, the forecast was extended to the year 2040 by assuming similar rates of growth. This extension allowed 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 2020 horizon is a rough approximation.

A range of demand forecasts was compared with the available resources for two scenarios. The *Baseline* scenario assumed the most likely growth forecast, current environmental flow recommendations, current levels of conservation (i.e., effects of *Energy Policy Act of 1992*) and water pricing rates, no effects of climate change on resources or demands, implementation of voluntary and mandatory restrictions as described on Section 4.9, upstream current and future consumptive demands, and a repeat of the drought of record. The *High Growth* scenario utilized the same assumptions as the *Baseline* scenario except that the MWCOG high estimates of population growth were used to develop the demand estimates.

Operations rules implemented in PRRSM model runs prevent Patuxent and Occoquan storage from dropping below emergency reserve storage levels. These rules prevented modeled reservoir storage in both Patuxent and Occoquan reservoirs from dropping below approximately 5 bg.

Table 6-3 shows the minimum remaining system storage as a function of forecast year for *Baseline* and *High Growth* scenarios. The minimum remaining system storage can be interpreted as the lowest Jennings Randolph and Little Seneca combined storage obtained in simulation model runs of 67 years of continuous flow data.

Table 6-3: Forecast year and minimum combined Jennings Randolph and Little Seneca storage for *Baseline* and *High-Growth* alternatives

Year	Minimum combined Jennings Randolph and Little Seneca reservoir storage (billion gallons; percent full)	
	Baseline scenario	*High Growth* scenario
2000	8.9 (52 %)	8.9 (52 %)
2010	6.7 (39 %)	6.2 (36 %)
2020	3.1 (18 %)	2.5 (15 %)
2030	1.5 (9 %)	0.2 (1 %)
2040	0 (0 %)	0.0 (0 %)

Table 6-3 shows that during a repeat of the worst drought of record (1930-1931), the minimum combined water supply storage in Jennings Randolph and Little Seneca under the *Baseline* scenario was 3.1 billion gallons (bg), given year 2020 demands and was 2.5 bg under the *High Growth* scenario. Given year 2030 demand, minimum combined Jennings Randolph and Little Seneca storage was 1.5 bg for the *Baseline* scenario and was 0.2 for the *High Growth* scenario. Minimum combined Jennings Randolph and Little Seneca storage was zero for both scenarios given 2040 levels of demand.

Table 6-4 shows the number of years in the historical record that modeled Jennings Randolph and Little Seneca combined storage was below 60 and 25 percent. Reservoir storage levels were examined for two scenarios, the *Baseline* and *High Growth*, for which the assumptions are described above.

Table 6-4: Number of years in the 67-year historical record that modeled Jennings Randolph and Little Seneca reservoir storage was below 60 and 25 percent thresholds

Year of demand forecast	*Baseline* scenario		*High Growth* scenario	
	Number of years modeled reservoir storage drops below 60 percent	Number of years modeled reservoir storage drops below 25 percent	Number of years modeled reservoir storage drops below 60 percent	Number of years modeled reservoir storage drops below 25 percent
2000	2/67	0/67	2/67	0/67
2010	2/67	0/67	2/67	0/67
2020	2/67	1/67	3/67	1/67
2030	3/67	2/67	4/67	2/67
2040	6/67	2/67	6/67	4/67

Table 6-4 shows that modeled Jennings Randolph and Little Seneca storage was below 60 percent full in 2 out of the 67 years of historical streamflow in the *Baseline* scenario given 2020 demand. Simulated storage was below 25 percent full in 1 out of 67 years for both scenarios given 2020 demand.

Given 2030 levels of demand, modeled reservoir storage was below 60 percent in 3 of 67 years for the *Baseline* scenarios and in 4 of 67 years for the *High Growth* scenario. Modeled reservoir storage was below 25 percent full for both *Baseline* and the *High Growth* alternatives in 2 of 67 years

Given 2040 levels of demand, modeled reservoir storage was below 60 percent in 6 of 67 years for both scenarios. Modeled reservoir storage was below 25 percent full in 2 of 67 years for the *Baseline* scenarios and in 4 of 67 years for the *High Growth* scenario.

6.11 Duration, magnitude, and frequency of low flows

The 1930-1931 drought was the longest drought in the historical record, and is the period in which modeled PRRSM reservoir storage was most depleted given 2020 demands. Figure 6-2 shows the magnitude and duration of simulated low flow in the Potomac if the drought of 1930-31 occurred in 2020. The modeled releases from Jennings Randolph and Little Seneca are shown as well. The model run assumptions for Figure 6-2 are the same as that described for the *Baseline* scenario discussed above in Section 6-10.

The legend in Figure 6-2 describes several flows and demands. These flows and demands are described in more detail below:

- "Potomac demands and flowby" is the WMA Potomac water supply demands that are estimated to occur in 2020, plus the current 100 mgd recommended minimum environmental flow. Note that the portion of the WMA water supply demand that is supplied by the Patuxent and Occoquan reservoirs is not included in the "Potomac demands and flowby" to better illustrate the comparison between flows and demands.

- "Jennings Randolph water supply release" is the simulated water *supply* release from Jennings Randolph Reservoir and does not include any water *quality* releases.

- "Seneca Release" is the simulated water supply release made from Little Seneca Reservoir.

- "River flow upstream of the WMA intakes" represents the flow that would be observed upstream of the WMA intakes if the drought of 1930 occurred in 2020. It is the historical river flow modified to include upstream human activities. Historical river flow was modified to incorporate: 1) flow releases from Jennings Randolph Reservoir for water quality, 2) estimated future releases from Broad Run and Little Seneca wastewater treatment plants, and 3) upstream consumptive demands that would be expected to occur in 2020. This flow does not include the releases from Jennings Randolph and Little Seneca for water supply demands.

- "River flow downstream of the WMA intakes" represents the flow that would be observed downstream of the WMA intakes if the drought of 1930 occurred in 2020. It is the historical river flow modified to include upstream human activities mentioned above (Jennings Randolph water quality releases, releases from upstream wastewater treatment plants, and upstream consumptive demands) and also the upstream WMA water withdrawals and water supply releases from Jennings Randolph and Little Seneca reservoirs.

Figure 6-2 shows that "Potomac demands and flowby" were constant after about mid October. Mandatory restrictions were implemented in the model runs in mid-October, forcing modeled water supply demands to remain constant at wintertime demand levels.

The simulated "River flow downstream of the WMA intakes" in Figure 6-2 was quite variable over the roughly three and a half month period during which modeled releases were made (July 16, 1930 to November 3, 1930). The simulated flow downstream of Little Falls varied from between 110 to 468 mgd over the release period. The simulated average and median flows over this time period were 183 mgd and 164 mgd respectively. The simulated river flow did not remain constant at the 100 mgd recommended flow target during the three months release period in part because of the inefficiency of Jennings Randolph operations as discussed in Section 6.4.

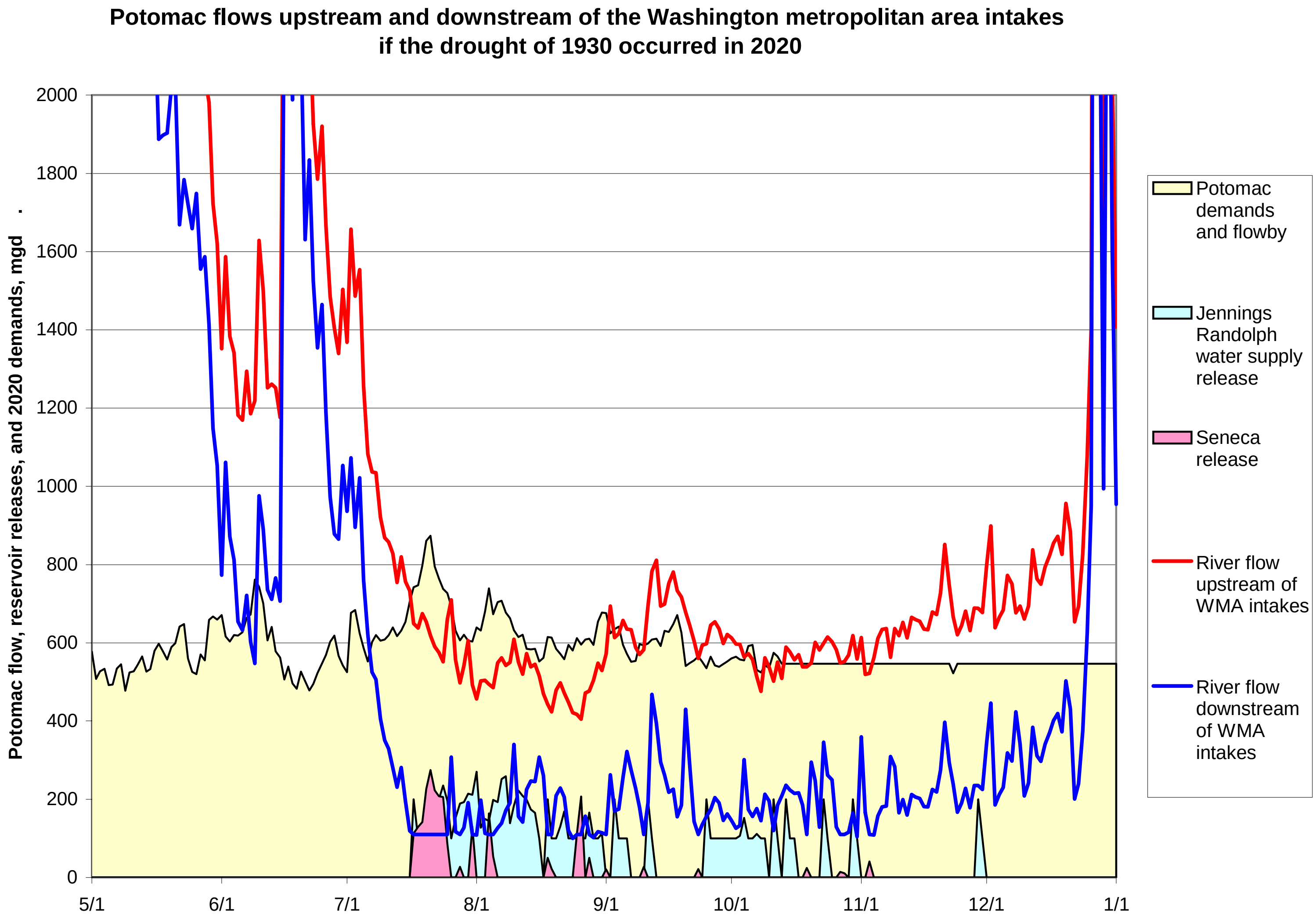

Figure 6-2. Potomac flows upstream and downstream of the WMA water supply intakes if the drought of 1930 occurred in 2020.

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The frequency and duration of simulated flow augmentation is presented in Table 6-5. This table describes each year in the historical record for which releases would have been required given current and future demands for the *Baseline* scenario. The total number of days in which releases would have been required for each year is also given.

Table 6-5: Years in historical record in which releases would have been required given 2000, 2020 and 2030 demands, and number of days of releases for each year, *Baseline* scenario

Year in historical record	2000 demands (number of days of releases)	2020 demands (number of days of releases)	2030 demands (number of days of releases)
1930	59	84	88
1931	-	1	12
1932	16	43	45
1934	-	1	4
1941	-	-	6
1944	-	6	16
1954	-	2	6
1957	12	25	31
1959	-	-	10
1962	-	-	2
1963	-	36	57
1964	6	14	28
1965	-	22	34
1966	46	54	58
1969	-	-	5
1977	-	-	2

The number of days of releases shown in Table 6-5 may not be consecutive. For example, the 84 days in which modeled releases were required under 1930 flow conditions and 2020 demands took place over the course of 102 days.

6.12 Sensitivity of system to changes in demand

A sensitivity analysis was conducted to determine how the system responds to changes in forecasts of demands. Table 6-6 gives the minimum remaining system storage for several alternative demand forecasts. The minimum remaining system storage can be interpreted as the lowest combined Jennings Randolph and Little Seneca storage obtained in simulation model runs over 67 years of continuous flow data.

Table 6-6: Remaining Jennings Randolph and Little Seneca storage for various alternative demand forecasts

Increase in average annual demand from 2000 to 2020 (million gallons per day)	Minimum combined system reservoir storage (billion gallons)
90	4.2
100 (most likely demand forecast)	3.1
126 (high growth demand forecast)	2.5
150	0.5
175	0

The most likely forecast of WMA growth corresponds to an average annual demand increase from 2000 to 2020 of approximately 100 mgd. The high forecast of growth corresponds to an average annual demand increase of approximately 126 mgd. Table 6-6 shows that the current system of reservoirs would be able to meet an increase in demand of up to 150 mgd under a repeat of 1930-1931 flow conditions, albeit with reserve storage at only 0.5 bg. The model run assumptions for Table 6-6 are the same as those described in Section 6.10.

6.13 Sensitivity of system to changes in resources

A sensitivity analysis was conducted to determine how the metro Washington water supply system responds to changes in resources. The sensitivity analysis was designed to answer the question, "How much lower would streamflow have to be before the system failed?" Streamflow resources were reduced by a straight percentage for the entire basin over the breadth of the flow record. Potomac flow and reservoir inflow rates were reduced by 5, 10, and 15 percent. System demands in the year 2020 were examined for the *Baseline* scenario as described in Section 6.10.

Table 6-7: Remaining Jennings Randolph and Little Seneca combined storage for various alternative reductions in resources, year 2020 demands, *Baseline* scenario

Percentage reduction in resources	Remaining Storage - Most likely forecast of 2020 demands (bg)
0	3.1
5	2.5
10	0.6
15	0

Table 6-7 shows that Jennings Randolph and Little Seneca could meet demands given a reduction in streamflow of 10 percent during the worst drought of the historical record under the *Baseline* scenario but would have only 0.6 bg of combined reserve storage.

6.14 Sensitivity of system to potential climate change

The sensitivity of the system to potential climate change was examined. The *Climate Change* scenario included higher demands as a result of potential climate change, combined with various percentage reduction in streamflow resources. (The *Climate Change* scenario development is described in more detail in Section 4.10.) The assumptions for the *Climate Change* scenario are the same as the *Baseline* scenario (as described in Section 6.10) except for an increase in 2020 demands of 9.5 percent during July through September and various reductions in streamflow resources. Table 6-8 gives the minimum remaining system storage for several alternative reductions in resources. The minimum remaining system storage can be interpreted as the lowest combined storage in Jennings Randolph and Little Seneca obtained in simulation model runs over 67 years of continuous flow data. A reduction of 10 percent in resources translates into a 10 percent reduction in Potomac flow and reservoir inflow.

Table 6-8: Remaining Jennings Randolph and Little Seneca combined storage for various alternative reductions in resources, year 2020 demands, *Climate Change* scenario

Percentage reduction in resources	Remaining Storage - Higher July –Sept, demands (bg)
0	2.1
5	0.4
10	0

Table 6-8 shows that Jennings Randolph and Little Seneca reservoirs could meet demands given a reduction in streamflow of 5 percent given the *Climate change* scenario but would have only 0.4 bg of combined reserve storage. Table 6-7 shows that given reductions in historical flows of over 5 percent, storage in Jennings Randolph and Savage reservoirs was depleted.

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

7 Summary of results and conclusions

The study was conducted in two parts. The first study element provides an estimate of the Washington metropolitan area (WMA) water supply demands in year 2020. The second major study element shows how the current system of rivers and reservoirs functions while meeting estimated future demands. The main focus of the study is to assess the ability of the regional water resources to meet the water supply needs of the WMA population as it continues to increase.

7.1 Results

Under the *most likely* population growth scenario, demands will increase by approximately 100 mgd for the CO-OP utilities from a current average annual water use of 480 mgd to 579 mgd, an increase of 21 percent. The *high growth* scenario results in an increase of annual water use from 480 mgd to 606 mgd, an increase of 126 mgd or 26 percent.

Although the MWCOG population forecast was for the year 2020, the forecast was extended to the year 2040 by assuming a continuation of similar rates of growth. This extension allowed 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 2020 horizon is a rough approximation.

A range of demand forecasts was compared with the available resources. The Occoquan and Patuxent reservoirs were used sustainably in model runs, with emergency reserve storage exceeding about 5 billion gallons at all times. Jennings Randolph and Little Seneca reservoirs (Potomac reservoirs) were used to augment Potomac flow in the model. Assuming a repeat of the drought of record, the following results were obtained:

- Using the *most likely* growth scenario, current resources met 2020 levels of demand with about 20 percent reserve storage in the Potomac reservoirs.
- Using the *most likely* growth scenario, current resources met 2030 levels of demand with about 10 percent reserve storage in the Potomac reservoirs.
- Using the *high growth* scenario, current resources met 2020 levels of demand with about 15 percent reserve storage in the Potomac reservoirs.
- Using the *high growth* scenario, current resources met 2030 levels of demand with about 1 percent reserve storage in the Potomac reservoirs.

Additional results were obtained from an investigation of model sensitivity analyses:

- Storage in the Potomac reservoirs was nearly depleted given the *most likely* forecast of 2020 demands and a reduction in streamflow resources of ten percent.

- The potential effects of climate change on resources were investigated but were not explicitly included because there was a lack of any clear climate change result for this region's resources.

- If climate change were to occur, demands could increase and streamflow resources could decrease relative to historical conditions. Resource sensitivity analysis indicates that given a reduction in historical streamflow of 5 percent and a 9.5 percent increase in June through September demands, the system of reservoirs could meet *most likely* 2020 demands but reserve storage would be nearly depleted.

- The average annual demand for the WMA is forecast to increase by approximately 100 mgd for the *most likely* scenario and approximately 126 mgd for the *high growth* scenario in the year 2020. Sensitivity analysis shows that the current system of reservoirs would be able to meet an increase in average annual demand of up to 150 mgd under a repeat of 1930-1931 flow conditions.

7.2 Conclusions

Two demand forecasts (*most likely* and *high growth* scenarios) were compared with the available resources. The Occoquan and Patuxent reservoirs were used sustainably in model runs, with emergency reserve storage exceeding about 5 billion gallons at all times. Jennings Randolph and Little Seneca reservoirs (Potomac reservoirs) were used to augment Potomac flow in the model. Assuming a repetition of the drought of record the following conclusions can be made:

- The current system of resources is adequate to meet the *most likely* and *high growth* estimates of 2020 demands even if the worst drought of record was to be repeated.

- Storage in the Potomac reservoirs was depleted given demands in excess of the *high growth* forecasts for 2030.

- Reserve storage in the Potomac reservoirs was sensitive to small reductions in the historical streamflow data.

- Climate change may have an impact on resources that would change the study results, especially given the sensitivity of Potomac reservoir storage to changes in historical streamflow data. Uncertainty in the current state of knowledge of future climate change precludes an acceptable forecast of what the effect on resources might be.

- Because of the current uncertainty and magnitude of impact of the potential effect of climate change on resources, future demand and resource studies might consider: 1) an examination of how extreme droughts might be influenced by potential climate change, and 2) a stochastic analysis to quantify the risks of experiencing a drought that is more extreme than historical observed droughts.

- A change in the minimum environmental flow rate might affect the results of the resource availability analysis.

- Demand forecasts could be higher than those used in the study if Congress repeals the *Energy Policy Act of 1992,* although local plumbing codes would control fixture ratings and may retain the conservation requirements contained within the Act for some jurisdictions.

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Appendix A - Production data for Washington Aqueduct

	1995	1996	1997	1998	1999	Mean
Average annual production, mgd	187	183	176	180	183	182
Winter water use (WWU), mgd	174	177	169	162	173	171
WWU production factor	0.93	0.97	0.96	0.90	0.94	0.94
Monthly average production, mgd						
January	171	181	175	159	183	174
February	171	178	173	155	171	169
March	168	177	173	160	170	170
April	172	179	170	167	169	171
May	175	183	172	171	182	176
June	194	194	157	189	206	188
July	210	198	213	204	222	209
August	223	196	207	207	206	208
September	207	188	172	215	181	193
October	189	182	178	188	175	183
November	178	173	165	178	168	172
December	180	172	158	173	165	170
Monthly average production factors						
January	0.91	0.99	0.99	0.88	1.00	0.95
February	0.92	0.97	0.98	0.86	0.93	0.93
March	0.90	0.96	0.98	0.89	0.93	0.93
April	0.92	0.98	0.96	0.92	0.92	0.94
May	0.94	1.00	0.98	0.95	0.99	0.97
June	1.04	1.06	0.89	1.05	1.12	1.03
July	1.12	1.08	1.21	1.13	1.21	1.15
August	1.20	1.07	1.17	1.15	1.13	1.14
September	1.11	1.02	0.98	1.19	0.99	1.06
October	1.01	0.99	1.01	1.04	0.95	1.00
November	0.96	0.94	0.94	0.99	0.92	0.95
December	0.96	0.94	0.90	0.96	0.90	0.93
Peak 1-day production, mgd						
January	207	215	213	183	204	204
February	187	222	200	190	191	198
March	183	201	213	190	197	197
April	223	206	187	198	194	201
May	208	210	211	208	232	214
June	233	219	178	239	263	227
July	246	222	277	240	281	253
August	257	224	269	243	231	245
September	238	207	188	250	205	218
October	212	215	206	221	202	211
November	203	189	199	194	187	194
December	206	206	175	206	184	195
Maximum 1-day demand	257	224	277	250	281	258

Appendix A - Production data for Washington Aqueduct

		1995	1996	1997	1998	1999	Mean
Peak 1-day production factors (peak/average monthly demands)							
	January	1.21	1.19	1.21	1.15	1.12	1.18
	February	1.09	1.25	1.16	1.23	1.12	1.17
	March	1.09	1.14	1.23	1.19	1.16	1.16
	April	1.30	1.15	1.10	1.19	1.14	1.17
	May	1.19	1.15	1.23	1.22	1.27	1.21
	June	1.20	1.13	1.13	1.27	1.28	1.20
	July	1.17	1.12	1.30	1.18	1.26	1.21
	August	1.15	1.14	1.30	1.17	1.12	1.18
	September	1.15	1.10	1.09	1.16	1.13	1.13
	October	1.12	1.18	1.16	1.18	1.15	1.16
	November	1.14	1.10	1.20	1.09	1.11	1.13
	December	1.14	1.20	1.11	1.19	1.12	1.15
Peak 7-day production, mgd							
	January	181	189	189	167	198	185
	February	176	193	178	163	179	178
	March	171	183	189	174	178	179
	April	180	192	176	175	176	180
	May	186	201	182	197	210	195
	June	211	204	184	212	227	208
	July	235	204	251	219	234	229
	August	239	206	230	230	228	227
	September	226	199	180	227	187	204
	October	197	190	195	197	182	192
	November	192	181	173	188	179	182
	December	187	184	165	186	171	179
Peak 7-day production factor (peak/average monthly demand)							
	January	1.06	1.05	1.08	1.05	1.09	1.06
	February	1.02	1.09	1.03	1.05	1.05	1.05
	March	1.02	1.03	1.09	1.09	1.05	1.06
	April	1.05	1.07	1.03	1.05	1.04	1.05
	May	1.06	1.10	1.06	1.16	1.16	1.11
	June	1.09	1.05	1.17	1.12	1.10	1.10
	July	1.12	1.03	1.18	1.08	1.05	1.09
	August	1.07	1.05	1.11	1.11	1.10	1.09
	September	1.09	1.06	1.05	1.06	1.03	1.06
	October	1.04	1.04	1.09	1.04	1.04	1.05
	November	1.08	1.05	1.05	1.06	1.06	1.06
	December	1.04	1.07	1.05	1.08	1.04	1.05
Average July 1 - October 31 production, mgd							
		207	191	193	203	196	198
July 1 - October 31 production factor, (Average July 1 - Oct. 31 production/annual average)							
		1.11	1.04	1.09	1.13	1.07	1.11

Appendix B - Production data for Fairfax County Water Authority

	1995	1996	1997	1998	1999	Mean
Average annual production, mgd	119	114	127	131	135	125
Winter water use (WWU), mgd	102	103	108	112	116	108
WWU production factor	0.86	0.91	0.85	0.86	0.86	0.86
Monthly average production, mgd						
January	104	101	108	110	119	108
February	103	102	105	108	112	106
March	106	102	105	112	114	108
April	120	111	112	119	121	117
May	119	115	124	131	150	128
June	127	130	145	136	172	142
July	139	127	172	157	177	154
August	162	130	163	169	162	157
September	140	119	137	160	133	138
October	112	113	129	131	124	122
November	103	108	116	121	122	114
December	100	106	110	118	118	110
Monthly average production factors						
January	0.87	0.89	0.85	0.84	0.88	0.86
February	0.86	0.89	0.83	0.82	0.82	0.85
March	0.89	0.89	0.82	0.85	0.84	0.86
April	1.00	0.98	0.88	0.91	0.89	0.93
May	0.99	1.02	0.98	1.00	1.11	1.02
June	1.06	1.15	1.14	1.04	1.27	1.13
July	1.16	1.11	1.35	1.19	1.31	1.23
August	1.36	1.14	1.28	1.29	1.20	1.25
September	1.17	1.05	1.08	1.22	0.98	1.10
October	0.94	0.99	1.01	1.00	0.91	0.97
November	0.86	0.95	0.92	0.93	0.90	0.91
December	0.83	0.93	0.86	0.90	0.87	0.88
Peak 1-day production, mgd						
January	112	108	120	122	132	119
February	111	111	111	117	121	114
March	117	110	118	134	127	121
April	137	127	126	129	133	130
May	139	139	163	180	184	161
June	154	151	192	152	221	174
July	176	149	214	179	208	185
August	185	139	211	202	192	186
September	190	153	170	197	149	172
October	121	122	149	147	134	135
November	113	117	127	137	128	124
December	107	120	119	136	131	123
Maximum 1-day demand	190	153	214	202	221	196

Appendix B - Production data for Fairfax County Water Authority

	1995	1996	1997	1998	1999	Mean
Peak 1-day production factors (peak/average monthly demands)						
January	1.08	1.07	1.11	1.11	1.11	1.10
February	1.08	1.09	1.06	1.08	1.09	1.08
March	1.10	1.08	1.13	1.19	1.11	1.12
April	1.14	1.14	1.12	1.08	1.10	1.12
May	1.18	1.21	1.31	1.37	1.23	1.26
June	1.21	1.16	1.32	1.12	1.28	1.22
July	1.27	1.18	1.25	1.14	1.17	1.20
August	1.14	1.07	1.30	1.19	1.18	1.18
September	1.35	1.29	1.24	1.23	1.12	1.25
October	1.08	1.08	1.16	1.12	1.08	1.11
November	1.10	1.09	1.09	1.13	1.05	1.09
December	1.07	1.13	1.08	1.15	1.11	1.11
Peak 7-day production, mgd						
January	107	104	113	113	122	112
February	104	106	107	110	113	108
March	112	105	110	121	118	113
April	124	119	115	123	133	123
May	129	129	152	153	180	148
June	140	135	170	151	207	161
July	174	135	208	171	194	176
August	176	140	184	183	180	173
September	177	135	149	183	141	157
October	116	115	144	135	126	127
November	107	110	120	128	124	118
December	101	108	115	124	123	114
Peak 7-day production factor (peak/average monthly demand)						
January	1.03	1.03	1.04	1.03	1.03	1.03
February	1.01	1.04	1.02	1.02	1.01	1.02
March	1.06	1.04	1.05	1.08	1.03	1.05
April	1.04	1.07	1.03	1.04	1.10	1.05
May	1.08	1.11	1.22	1.17	1.20	1.16
June	1.11	1.04	1.17	1.11	1.20	1.13
July	1.26	1.07	1.21	1.09	1.09	1.14
August	1.09	1.08	1.13	1.08	1.11	1.10
September	1.26	1.13	1.09	1.15	1.06	1.14
October	1.04	1.02	1.12	1.03	1.02	1.05
November	1.04	1.02	1.03	1.05	1.02	1.03
December	1.02	1.02	1.05	1.05	1.05	1.04
Average July 1 - October 31 production, mgd						
	138	122	150	154	149	143
July 1 - October 31 production factor, (Average July 1 - Oct. 31 production/annual average)						
	1.16	1.07	1.18	1.18	1.10	1.13

Appendix C - Production data for Washington Suburban Sanitary Commission

	1995	1996	1997	1998	1999	Mean
Average annual production, mgd	167	161	165	166	168	165
Winter water use (WWU), mgd	157	158	151	149	155	154
WWU production factor	0.94	0.98	0.92	0.90	0.92	0.93
Monthly average production, mgd						
January	158	164	154	147	159	157
February	159	161	151	146	151	154
March	157	155	149	149	154	153
April	162	157	158	155	158	158
May	161	163	166	168	185	169
June	170	174	173	173	204	179
July	183	170	196	192	207	189
August	200	169	191	195	174	186
September	182	165	172	190	161	174
October	160	158	163	167	156	161
November	157	151	152	161	154	155
December	155	149	148	155	153	152
Monthly average production factors						
January	0.95	1.01	0.94	0.89	0.95	0.95
February	0.95	1.00	0.92	0.88	0.90	0.93
March	0.94	0.96	0.91	0.90	0.92	0.93
April	0.97	0.98	0.96	0.93	0.94	0.96
May	0.96	1.01	1.01	1.01	1.10	1.02
June	1.02	1.08	1.05	1.04	1.22	1.08
July	1.10	1.05	1.19	1.15	1.23	1.14
August	1.20	1.05	1.16	1.17	1.03	1.12
September	1.09	1.02	1.05	1.14	0.96	1.05
October	0.96	0.98	0.99	1.00	0.93	0.97
November	0.94	0.93	0.92	0.97	0.91	0.94
December	0.93	0.92	0.90	0.93	0.91	0.92
Peak 1-day production, mgd						
January	172	180	193	158	173	175
February	171	172	167	158	160	166
March	171	199	160	164	165	172
April	179	170	181	166	169	173
May	185	192	191	200	225	199
June	199	198	199	194	263	211
July	223	185	246	209	231	219
August	234	190	231	220	216	218
September	218	181	193	217	176	197
October	180	172	184	183	170	178
November	173	159	166	179	164	168
December	170	160	158	170	183	168
Maximum 1-day demand	234	199	246	220	263	232

Appendix C - Production data for Washington Suburban Sanitary Commission

	1995	1996	1997	1998	1999	Mean
Peak 1-day production factors (peak/average monthly demands)						
January	1.09	1.10	1.25	1.07	1.09	1.12
February	1.08	1.07	1.10	1.08	1.06	1.08
March	1.08	1.28	1.07	1.10	1.07	1.12
April	1.11	1.08	1.14	1.07	1.07	1.10
May	1.15	1.18	1.15	1.19	1.22	1.18
June	1.17	1.14	1.15	1.12	1.29	1.17
July	1.22	1.09	1.25	1.09	1.11	1.15
August	1.17	1.12	1.21	1.13	1.25	1.18
September	1.19	1.10	1.12	1.14	1.09	1.13
October	1.12	1.09	1.13	1.10	1.09	1.11
November	1.10	1.06	1.09	1.11	1.07	1.09
December	1.09	1.07	1.07	1.10	1.19	1.11
Peak 7-day production, mgd						
January	162	172	167	149	165	163
February	162	165	156	148	156	157
March	160	170	151	156	156	158
April	165	161	169	162	169	165
May	168	177	179	184	213	184
June	182	182	189	182	239	195
July	215	174	228	201	220	208
August	218	176	211	210	205	204
September	208	174	179	210	165	187
October	164	160	175	171	158	166
November	160	155	157	163	158	158
December	159	153	150	163	163	158
Peak 7-day production factor (peak/average monthly demand)						
January	1.03	1.05	1.08	1.01	1.04	1.04
February	1.02	1.03	1.03	1.01	1.03	1.03
March	1.02	1.09	1.01	1.04	1.01	1.04
April	1.02	1.02	1.07	1.04	1.07	1.04
May	1.04	1.09	1.08	1.10	1.15	1.09
June	1.07	1.05	1.09	1.05	1.17	1.09
July	1.17	1.03	1.16	1.05	1.06	1.10
August	1.09	1.04	1.11	1.08	1.18	1.10
September	1.14	1.05	1.04	1.10	1.02	1.07
October	1.03	1.01	1.07	1.03	1.01	1.03
November	1.02	1.03	1.03	1.01	1.03	1.02
December	1.03	1.03	1.02	1.05	1.07	1.04
Average July 1 - October 31 production, mgd						
	181	165	181	186	175	178
July 1 - October 31 production factor, (Average July 1 - Oct. 31 production/annual average)						
	1.09	1.03	1.10	1.12	1.04	1.09

Appendix D - Production data for CO-OP system

	1995	1996	1997	1998	1999	Mean
Average annual production, mgd	473	458	468	478	486	473
Winter water use (WWU), mgd	433	438	427	424	443	433
WWU production factor	0.92	0.95	0.91	0.89	0.91	0.92
Monthly average production, mgd						
January	432	446	437	416	460	438
February	433	440	429	408	434	429
March	432	434	427	421	438	431
April	454	448	440	440	449	446
May	454	461	463	469	517	473
June	491	499	476	498	582	509
July	531	494	581	552	607	553
August	585	495	560	571	542	551
September	530	472	482	565	475	505
October	461	453	470	486	454	465
November	438	431	434	460	444	441
December	435	427	415	446	436	432
Monthly average production factors						
January	0.91	0.97	0.93	0.87	0.95	0.93
February	0.92	0.96	0.92	0.85	0.89	0.91
March	0.91	0.95	0.91	0.88	0.90	0.91
April	0.96	0.98	0.94	0.92	0.92	0.94
May	0.96	1.01	0.99	0.98	1.06	1.00
June	1.04	1.09	1.02	1.04	1.20	1.08
July	1.12	1.08	1.24	1.15	1.25	1.17
August	1.24	1.08	1.20	1.20	1.11	1.16
September	1.12	1.03	1.03	1.18	0.98	1.07
October	0.98	0.99	1.01	1.02	0.93	0.98
November	0.93	0.94	0.93	0.96	0.91	0.93
December	0.92	0.93	0.89	0.93	0.90	0.91
Peak 1-day production, mgd						
January	482	471	497	446	502	480
February	449	492	458	434	457	458
March	458	464	465	452	466	461
April	531	496	470	488	493	495
May	524	525	555	570	594	554
June	586	537	540	575	741	596
July	631	531	704	626	708	640
August	676	549	699	656	618	640
September	617	529	534	642	514	567
October	491	504	529	530	498	510
November	463	460	461	499	463	469
December	468	468	441	501	485	473
Maximum 1-day demand	676	549	704	656	741	665

Appendix D - Production data for CO-OP system

	1995	1996	1997	1998	1999	Mean
Peak 1-day production factors (peak/average monthly demands)						
January	1.11	1.06	1.14	1.07	1.09	1.09
February	1.04	1.12	1.07	1.06	1.05	1.07
March	1.06	1.07	1.09	1.07	1.06	1.07
April	1.17	1.11	1.07	1.11	1.10	1.11
May	1.15	1.14	1.20	1.21	1.15	1.17
June	1.19	1.08	1.14	1.16	1.27	1.17
July	1.19	1.07	1.21	1.13	1.17	1.16
August	1.16	1.11	1.25	1.15	1.14	1.16
September	1.16	1.12	1.11	1.14	1.08	1.12
October	1.06	1.11	1.12	1.09	1.10	1.10
November	1.06	1.07	1.06	1.08	1.04	1.06
December	1.08	1.09	1.06	1.12	1.11	1.09
Peak 7-day production, mgd						
January	446	457	466	425	483	456
February	440	462	437	415	446	440
March	439	448	443	448	447	445
April	468	469	458	456	477	466
May	478	507	511	534	600	526
June	526	514	518	530	672	552
July	624	509	680	587	642	608
August	634	517	625	622	607	601
September	604	503	504	614	492	544
October	474	462	513	498	465	482
November	452	440	446	478	455	454
December	446	435	428	469	456	447
Peak 7-day production factor (peak/average monthly demand)						
January	1.03	1.02	1.07	1.02	1.05	1.04
February	1.02	1.05	1.02	1.02	1.03	1.03
March	1.02	1.03	1.04	1.06	1.02	1.03
April	1.03	1.05	1.04	1.04	1.06	1.04
May	1.05	1.10	1.10	1.14	1.16	1.11
June	1.07	1.03	1.09	1.06	1.15	1.08
July	1.17	1.03	1.17	1.06	1.06	1.10
August	1.08	1.04	1.12	1.09	1.12	1.09
September	1.14	1.07	1.05	1.09	1.04	1.08
October	1.03	1.02	1.09	1.03	1.02	1.04
November	1.03	1.02	1.03	1.04	1.03	1.03
December	1.03	1.02	1.03	1.05	1.04	1.03
Average July 1 - October 31 production, mgd						
	527	478	524	543	520	518
July 1 - October 31 production factor, (Average July 1 - Oct. 31 production/annual average)						
	1.11	1.04	1.12	1.14	1.07	1.11

Appendix E: Summary of household, population, and employment statistics

Round 6.1 Cooperative Forecasts for 1990-2020

Based on estimated present (2000) and future (2020) utility service areas overlay with MWCOG Traffic Analysis Zones (TAZs)

	Totals for 2000			Totals for 2020		
	Households	Population	Employment	Households	Population	Employment
FCWA - Dulles	-	-	14,339	-	-	20,723
FCWA - Ft. Belvoir	2,152	12,258	24,880	4,399	18,132	39,038
FCWA - Herndon	7,034	18,984	21,872	10,508	27,470	26,882
FCWA - Lorton	1	6,493	934	1	6,493	528
FCWA - Loudoun Sanitation Authority	33,409	94,002	34,220	90,693	247,241	87,694
FCWA - Prince William Service Authority	57,418	173,438	63,606	97,823	282,709	112,145
FCWA - Retail service area	276,507	751,433	348,041	341,564	919,371	473,944
FCWA - Virginia American - Alexandria	61,522	127,096	98,552	68,609	140,870	115,890
FCWA - Virginia American - Dale City	17,840	53,877	8,740	19,102	55,206	10,126
FCWA subtotal	455,883	1,237,581	615,184	632,700	1,697,491	886,969
WAD: Arlington County DPW	89,851	189,272	162,109	103,865	210,206	234,979
WAD: WASA	221,796	518,100	678,014	256,305	618,611	776,804
WAD: Falls Church	48,238	120,343	114,460	57,635	141,597	142,174
WAD: Falls Church: Vienna	9,317	26,638	12,797	10,413	29,648	13,610
WAD: WASA: National	-	-	9,938	-	-	9,938
WAD: WASA: Arlington Cem., Pentagon, Ft. Myer	251	2,719	29,184	249	2,690	30,464
WAD subtotal	369,453	857,072	1,006,502	428,467	1,002,752	1,207,968
WSSC: Montgomery County	291,301	786,208	439,776	364,736	931,715	564,746
WSSC: Prince George's County	277,154	747,652	311,816	341,132	882,059	435,545
WSSC subtotal	568,455	1,533,859	751,592	705,868	1,813,774	1,000,291
FCWA, WAD, WSSC total	1,393,791	3,628,513	2,373,278	1,767,035	4,514,017	3,095,229
Rockville	15,030	41,670	65,308	16,603	43,551	75,820
FCWA, WAD, WSSC, Rockville total	1,408,821	3,670,183	2,438,586	1,783,638	4,557,568	3,171,049

Appendix J. Calculation of unit use factor

Fairfax County Water Authority

Unmetered water use

The net water billed in FCWA's direct service area in 1998 was 71.25 mgd on average. (Jamie Bain, FCWA, personal communication , December 6, 1999). The amount of water sold to wholesale customers was 44.9 mgd on average, for a total of 116.2 mgd of water billed directly in its service area or sold to wholesale customers in 1998. The total water produced at the Occoquan and Potomac treatment plants was 131.1 mgd. The difference of 15.0 mgd (11.4%) comprises the unmetered or unaccounted/non-revenue category.

Billing records

FCWA uses several service classifications including single family houses, townhouses, apartments, commercial/industrial, and municipal categories. This makes dissagregation of demands into single family, multi-family and employment categories fairly straightforward.

Determination of single and multi-family unit use factors

FCWA reports 33.8 mgd billed in its single family dwelling water use category in 1998, 10.4 mgd billed in its townhouse water use category, and 12.2 mgd billed in its multi-family category in 1998. The single family and townhouse water use categories were combined into the single family residence category for a total demand of 44.2 mgd. The number of 1998 households in the FCWA's direct service area is 265,875 as based on a GIS overlay of FCWA's direct service area with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. Applying the dwelling unit ratio of 3.18 (number of single family residences divided by number of multi-family residences) to the number of 1998 households in the FCWA service area yields 202,261 single family households and 63,614 multi-family households. The FCWA unit use for single-family residences is 218.6 gallons per day per household, as based on 33.8 mgd over 202,261 households. The FCWA unit use for multi-family households is 191.8 gallons per household per day as based on 12.2 mgd used by 63,614 multi-family households.

According to an FCWA analysis, the per household consumption for single family dwellings was 236 mgd and for townhouses 186 mgd in 1998 (Jamie Bain, FCWA, personal communication , December 6, 1999). Combining the volume of water sold in 1998 to both single family dwellings and townhouses and dividing by the FCWA estimate of the number of total single family and townhouse connections yields an average per household water use of 221.8 mgd. This result is within 1.5% of the 218.6 gallon per household per day estimate derived by ICPRB using traffic analysis zones and dwelling unit ratios.

Determination of employee unit use factors

FCWA reports that there was 12.6 mgd of water used in the commercial category and 2.2 mgd used in the municipal category in 1998. The FCWA commercial and municipal categories were combined into a single commercial category with a total water use of 14.8 mgd. The number of 1998 employees in the FCWA service area is 323,846 as based on a GIS overlay of FCWA's service area with traffic analysis zones, extracting the 1995 and 2000 employment data and interpolating for 1998. The per employee daily water use is thus calculated as 45.8 gallons per day.

Notes

FCWA notes an industrial water use of 0.1 mgd of untreated water sold to Vulcan in 1998. If future water use by Vulcan increases significantly, this water demand should be accounted for in future resource availability analyses. FCWA also notes sale of 0.04 mgd to Prince William County Parks. These numbers are currently offset by water produced by FCWA wells. In the last few years, FCWA has shut down some of its wells; only two well systems remain in operation, and their average production for 1998 and 1999 was 0.105 mgd. A direct accounting of well production and untreated water sold to Vulcan and Prince William County Parks was not conducted, since the total water use and production for these categories is insignificant and furthermore cancels each other out when considered together.

FCWA - Prince William County Service Authority (PWCSA)

Unmetered water use

PWCSA relies on several sources of water (R.B. Caire, PWSCA, personal communication , December 21, 1999). In 1998, the PWSCA purchased on average 13.0 mgd from FCWA. Current well production in the western area of their service area is approximately 2 mgd. PWSCA purchases water from the City of Manassas, averaging about 3.4 mgd from July of 1998 through November of 1999. (The PWSCA does sell some water back to the City of Manassas, varying from 0.2 to 0.9 mgd.) The net water produced from wells or net water bought from Manassas and FCWA totaled 17.8 mgd on average. The unaccounted for water reported by PWSCA is approximately 1 mgd, or 5.6% of 17.8 mgd.

Billing records

PWSCA uses residential, commercial, and unaccounted for water use categories. PWSCA's residential water use category combines both single family dwellings and multi-family residences, as water billing records are not disaggregated by type of residence. Disaggregating demands into single and multi-family residential use requires making some assumptions about water use within either the single-family or multi-family category.

Determination of single and multi-family unit use factors

Unit use factors for PWSCA were calculated using the following method. 13.67 mgd was billed to the residential category (single family and multi family households) in 1998. The number of 1998 households in the PWSCA service area is 54,482, as based on a GIS overlay of PWSCA's service area with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. Applying the dwelling unit ratio of 4.39 (number of single family residences divided by number of multi-family residences) to the number of 1998 households in the PWSCA service area yields 44,371 single family households and 10,111 multi-family households. The multi-family unit use factor developed for FCWA's direct service area of 191.8 gallons per day per household was assumed for PWSCA's multi-family residences. Applying the FCWA multi-family unit use factor to the 10,111 multi-family households yields a total water use of 1.94 mgd. Subtracting this assumed multi-family use from PWSCA's total residential use (13.67 - 1.94) yields a total single family water use of 11.73 mgd, or 264.4 gallons per household per day (assuming the value of 44,371 single family households in the PWSCA service area).

Determination of employee unit use factors

PWSCA reports that there was 3.74 mgd water used in the commercial category. (The commercial category as defined for PWSCA includes offices, businesses, industrial water use, governments, and schools.) The number of 1998 employees in the PWSCA service area is 59,657 as based on a GIS overlay of PWSCA's service area with traffic analysis zones, extracting the 1995 and 2000 employment data and interpolating for 1998. The per employee daily water use is thus calculated as 62.7 gallons per day.

Notes

Note that the PWSCA has capacity rights to 5 mgd from the City of Manassas and 37.5 mgd from Fairfax County Water Authority.

FCWA - Virginia American – Alexandria City

Unmetered water use

Virginia American relies on water purchased from FCWA (Bill Walsh, Virginia American, personal communication , November 9, 1999). In 1998, Virginia American purchased on average 16.3 mgd from FCWA for the Alexandria City service area. The unaccounted for water reported by Virginia American is approximately 0.53 mgd, or 4.2% of 16.3.

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 as well as some water sold wholesale to Prince William County Service Authority.

Determination of single family unit use factor

The single family unit use factor for Virginia American was calculated using the following method. 3.8 mgd was billed to the residential category (single family households) in 1998. The number of 1998 households in the Virginia American service area is 59,482 as based on a GIS overlay of Virginia American's Alexandria service area with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. Applying the dwelling unit ratio of 0.45 (number of single family residences divided by number of multi-family residences) to the number of 1998 households in the Virginia American service area yields 18,537 single family households and 40,945 multi-family households. The single-family water use factor was thus 204.4 gallons per household per day (assuming 3.8 mgd billed to 18,537 single family households).

Determination of multi-family and employee unit use factor

Virginia American's commercial category includes multi-family dwellings, office and other commercial water uses. 10.4 mgd was billed to the commercial category, 0.54 mgd to the industrial category, and 0.80 to the "other" category in 1998. The "other" category consists of governmental/municipal water use. The total water use in the combined categories of commercial, industrial, and "other" is 11.8 mgd. The per-employee unit use factor developed for FCWA's direct service area of 45.8 gallons per day per employee was assumed for the Virginia American service area. The number of 1998 employees in the Virginia American service area is 95,908 as based on a GIS overlay of Virginia American's service area with traffic analysis zones, extracting the 1995 and 2000 employment data and interpolating for 1998. Applying the FCWA per-employee- unit use factor to the 95,908 employees yields a total water use of 4.4 mgd. Subtracting this assumed employee water use from Virginia American's total commercial, industrial and "other" use yields 7.4 mgd (11.8-4.4). The remaining 7.4 mgd was the net water use assumed for the multi-family category. Given 40,945 multi-family households in the Virginia American service area as calculated above, a multi family unit use was derived as 180.5 gallons per household per day (7.4 mgd over 40,945 households).

FCWA - Virginia American- Dale City

Unmetered water use

Virginia American relies on water purchased from FCWA (Bill Walsh, Virginia American, personal communication , November 9, 1999). In 1998, Virginia American purchased on average 4.5 mgd from FCWA for the Dale City service area. The unaccounted for water reported by Virginia American for Dale City is approximately 0.33 mgd, or 7.3% of 4.5 mgd.

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

The single family unit use factor for Virginia American was calculated using the following method. 3.2 mgd was billed to the residential category (single family households) in 1998. The number of 1998 households in the Virginia American service area is 17,342 as based on a GIS overlay of Virginia American's Dale City service area with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. Applying the dwelling unit ratio of 10.93 (number of single family residences divided by number of multi-family residences) to the number of 1998 households in the Virginia American service area yields 15,888 single family households and 1,454 multi-family households. The single-family water use factor was thus 199.9 gallons per household per day (assuming 3.2 mgd billed to 15,888 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 1998, 0.48 mgd was billed to the commercial category, 0 mgd to the industrial category, and 0.55 to the "other" category in 1998. The "other" category consists of governmental/municipal water use. The total water use in the combined categories of commercial, industrial, and "other" is 1.02 mgd. The multi-family unit use factor developed for FCWA's direct service area of 191.8 gallons per household per day was assumed for the Virginia American service area. The number of 1998 multi-family households in the Virginia American service area is 1,454 as calculated above. Applying the FCWA multi-family unit use factor to the 1,454 households yields a total water use of 0.28 mgd. Subtracting this assumed employee water use from Virginia American's total commercial, industrial and "other" use yields 0.75 mgd (1.02-0.28). The remaining 0.75 mgd was the net water use assumed for the employee category. The number of 1998 employees in the Virginia American service area is 8,453 as based on a GIS overlay of Virginia American's service area with traffic analysis zones, extracting the 1995 and 2000 employment data and interpolating for 1998. Given 8,453 employees in the Virginia American service area as calculated above, a per employee unit use was derived as 88.2 gallons per employee per day.

FCWA - Loudoun County Sanitation Authority

Unmetered water use

LCSA purchases water from FCWA and the City of Fairfax, and tracks water use for such purposes as fire hydrant flushing and construction purposes. The LCSA water system is fairly new (50% of the pipes are less than 8 years old) (Timothy Coughlin, LCSA, personal communication, December 7, 1999). The net water bought from the City of Fairfax and FCWA in 1998 totaled 9.63 mgd on average. (The total average water purchased from FCWA was 4.0 mgd and from City of Fairfax 5.6 mgd.) A total of 9.36 mgd was billed in 1998. A total of 0.27 mgd was permitted for unmetered withdrawals, for a total of 2.9% unmetered water use.

Billing records

LCSA uses *residential*, *apartments, commercial/industrial*, and *consturction/fire hydrant water use(permit)* for its water use categories. LCSA's residential water use category combines both single family dwellings and townhomes.

Determination of single and multi-family unit use factors

Unit use factors for LCSA were calculated using the following method. In 1998, 7.60 mgd was billed to the residential category (single family and townhouses). The number of 1998 households in the LCSA service area is 28,989, as based on a GIS overlay of LCSA's service area with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. Applying the dwelling unit ratio of 4.98 (number of single family residences divided by number of multi-family residences) to the number of 1998 households in the LCSA service area yields 24,141 single family households and 4,848 multi-family households. These numbers are slightly lower than the 27,600 single family dwellings (connections) and 5,543 apartments estimated by LCSA for 1998).

The number of existing houses provided in the Round 6.1 Cooperative Forecasts for 1990-2020 for Loudoun County is estimated to be too low (Tim Canaan, Loudoun County Department of Planning, personal communication, December 21, 1999). Furthermore, the LSCA authorities number is further validated in planning documents (County of Loudoun, 1999) Therefore, the unit use factors were developed as based on the Loudoun County data for numbers of connections and apartment units served.

The single-family water use factor was thus 275.4 gallons per household per day (assuming 7.6 mgd billed to 27,600 single family households). In 1998, 0.88 mgd was billed to the apartment category. The multi-family water use factor was thus 158.8 gallons per household per day (assuming 0.88 mgd billed to 5,543 apartments).

Reference: County of Loudoun, 1999. *1998 Annual Update*. . Report by the Fiscal Impact Analysis Technical Review Committee. Leesburg, VA.

Determination of employee unit use factors

LCSA reports that there was 0.88 mgd water used in the commercial/industrial category of water use. The number of 1998 employees in the LCSA service area is 29,507 as based on a GIS overlay of LCSA's service area with traffic analysis zones, extracting the 1995 and 2000 employment data and interpolating for 1998. The per employee daily water use is thus calculated as 29.8 gallons per day.

Notes

LCSA reports that an agreement with the City of Fairfax limits average water consumption to 7 mgd, which means that all future water demands above 7 mgd can be assumed to come from FCWA (Timothy Coughlin, LCSA, personal communication, December 7, 1999).

FCWA - Herndon

Unmetered water use and billing records

The Town of Herndon purchases water from FCWA. The net water bought from the FCWA in 1998 totaled 2.1 mgd on average. No billing records were obtained for the Town of Herndon, 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 FCWA's direct supply service area (11.4%).

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

Unit use factors for the Town of Herndon were calculated using the following method. The multi-family and per employee unit use was assumed to be the same as for that of FCWA's direct service area (218.6 gallons per multi-family household and 191.8 galllons per household per day). In 1998, 2.1 mgd was sold to the Town of Herndon. Assuming an 11.4% unmetered water use, 1.9 mgd was available. The number of 1998 households in the Town of Herndon's service area is 6,657 and the number of employees is 20,405 as based on a GIS overlay of the Town of Herndon's service area with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. Applying the dwelling unit ratio of 3.18 (number of single family residences divided by number of multi-family residences) to the number of 1998 households in the Town of Herndon's service area yields 5,064 single family households and 1,593 multi-family households. The total water use for multi-family households was estimated to be 1.11 mgd (218.6 gallons per household per day times 5,064 households). The total water use for multi-family households was estimated to be 0.31 mgd (191.8 gallons per household per day times 1,593 households). The total remaining water available employee use was 0.48 mgd.

The per employee water use factor was thus calculated to be 23.4 gallons per employee per day (assuming 0.48 mgd used by 20,405 employees).

FCWA – Fort Belvoir

Unmetered water use and billing records

Fort Belvoir purchases water from FCWA. The net water bought from the FCWA in 1998 totaled 1.8 mgd on average. No billing records were obtained for Fort Belvoir, 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 FCWA's direct supply service area (11.4%).

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

Unit use factors for Fort Belvoir were calculated using the following method. The single and multi-family unit use ratese were assumed to be the same as for that of FCWA's direct service area (218.6 gallons per multi-family household and 191.8 galllons per household per day). In 1998, 1.8 mgd was sold to Fort Belvoir. Assuming an 11.4% unmetered water use, 1.6 mgd was available. The number of 1998 households in Fort Belvoir's service area is 1,622 and the number of employees is 24,134 as based on a GIS overlay of Fort Belvoir's service area with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. Applying the FCWA direct service area dwelling unit ratio of 3.18 (number of single family residences divided by number of multi-family residences) to the number of 1998 households in Fort Belvoir service area yields 1,234 single family households and 388 multi-family households. The total water use for households was estimated to be 0.27 mgd for single family and 0.07 mgd for multi-family. The employee unit use rate was calculated by subtracting unmetered, single and multi-family water uses from the total amount sold to Fort Belvoir and dividing by the number of employees. The per employee unit use was calculated as 50.1 gallons per person per day.

FCWA - Lorton

Unmetered water use

Lorton purchases water from FCWA. The net water bought from the FCWA in 1998 totaled 1.1 mgd on average. No billing records were obtained from Lorton, 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 FCWA's direct supply service area (11.4%).

Billing records

Billing records for Lorton were not obtained.

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

Unit use factors for Lorton were calculated using the following method. The number of 2000 households in the Lorton service area is 1, so water use for households in the Lorton TAZ zones was assumed to be zero. The number of employees is 1,052 as based on a GIS overlay of the Lorton service area with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. The prisoner population was estimated using population estimates as follows. The number of prisoners is 6,809 as based on a GIS overlay of the Lorton service area with traffic analysis zones, extracting the 1995 and 2000 population data and interpolating for 1998. The combined prisoner/employee 1998 count was 7,861. The per person water use rate was calculated as 0.95 mgd over 7,861 people, resulting in a per-capita water use of 120.9 gallons per person per day. Note that Lorton has closed and is being replaced by a water treatment plant. Water use employee rates for 2000 and beyond were assumed to be the same as for FCWA's broader service area (45.8 gallons per employee per day).

FCWA - Dulles

Unmetered water use

Dulles purchases water from FCWA. The net water bought from the FCWA in 1998 totaled 0.7 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 that of FCWA's, or 11.9%.

Billing records

Billing records for the Dulles were not obtained.

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

Unit use factors for Dulles were calculated using the following method. The number of 2000 households in the Dulles service area is 1, so water use for households in the Dulles service area was assumed to be zero. The number of employees is 13,061 as based on a GIS overlay of the Dulles service area with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. The per employee water use rate was calculated as 0.63 mgd divided by 13,061 people, resulting in a per-employee water use of 47.9 gallons per person per day.

WAD - DC Water and Sewer Authority (WASA)

Unmetered water use

WASA relies on water purchased from WAD. In 1998, WASA purchased on average 134.6 mgd from WAD. The water billed in 1998 was 98.9 mgd. A total of 2.2 mgd was assumed sold to Reagan National Airport, the Pentagon, Arlington Cemetery, and Fort Myer. A total of 1.7 mgd of the water sold to WAD was returned to the McMillan plant for filter backwash purposes. The net water bought from WAD for distribution in DC was 130.7 mgd (134.6 – 2.2 – 1.7). The unaccounted for water is the difference between 130.7 and 98.9, or 31.8 mgd.

Billing records

WASA uses residential, commercial, DC Government, and Federal buildings for its water use categories. WASA's residential water use category includes single family dwellings, condos, and townhouses. 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.

Determination of multi-family and single family unit use factors

Uncertainty in the number of single family vs. multi family households resulted in a single unit use factor being calculated for the WASA service area, for both single and multi-family residences. The total amount of water billed by WASA for its commercial and residential water use categories was 68.8 mgd. The number of 1998 households in the WASA service area is 225,916 households as based on a GIS overlay of WASA's service area with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. The single- and multi-family use factor was thus 304.4 gallons per household per day.

Determination of employee unit use factor

WASA's DC Government and Federal buildings categories were combined. In 1998, 30.1 mgd was billed to both categories. The number of 1998 employees in the WASA service area is 687,569 as based on a GIS overlay of WASA's service area with traffic analysis zones, extracting the 1995 and 2000 employment data and interpolating for 1998. Given 687,569 employees in the WASA service area as calculated above, a per employee unit use was derived as 43.8 gallons per employee per day.

WAD – WASA – Reagan National, Pentagon, Arlington cemetery, Fort Myer

Unmetered water use and billing records

Reagan National, Pentagon, Arlington cemetery and Fort Myer rely on water purchased from WAD by way of WASA. Billing records were not gathered for these water users. An unaccounted water use of 11.4% was assumed.

Determination of multi-family and single family unit use factors

There are no households in the Reagan National service area, and a per employee unit use equal to Dulles's per employee rate of 47.9 gallons per day was assumed. For the Pentagon, Arlington cemetery, and Fort Myer employees a water use rate equal to Fort Belvoir's per employee rate was assumed (50.1 gallons per employee per day). The number of households in the combined Pentagon, Arlington cemetery, and Fort Myer service areas was 251 in 1998. A per household unit use of 185 gallons per household per day was assumed, equal to nearby Arlington County DPW's single family household rate.

WAD - Falls Church DES and Vienna DPW

Billing records

Monthly billing information for each category was obtained from the Falls Church DES. Falls Church DES uses single family dwelling, townhouse, apartment, commercial, and municipal categories to describe its customer water use. However, large fluctuations in the amount of water billed for each category of water use by month made this data not useful for the purposes of calculating unit use numbers or for calculating unaccounted for water percentages. Therefore, unit use rates for single family and multi family residences were assumed using FCWA unit use numbers, the unaccounted for water use percentage was assumed, and the employee unit use was calculated as follows.

Unmetered water use

The City of Falls Church Department of Environmental Services/ Public Utilities Division (Falls Church DES) relies on water purchased from WAD. In turn, Falls Church DES wholesales a small amount of this water to Vienna DPW. In 1998, Falls Church DES purchased on average 16.3 mgd from WAD. Vienna purchased 1.7 mgd of water from Falls Church in 1998, and 0.79 mgd from FCWA. The percentage of unaccounted for water was assumed to be the same as for FCWA, 11.4%. The unaccounted for water was calculated as 11.4% of 17.1 (17.1 equals 16.3 plus 0.79 mgd) for a total of 1.95 mgd.

Determination of multi-family and single family unit use factors

The number of 1998 households in the combined Falls Church and Vienna service areas is 55,583 as based on a GIS overlay of the service areas with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. The number of 1998 households in the Falls Church service area is 46,527 and 9,056 in the Vienna service area.

The number of single family and multi-family households in the Falls Church service area was calculated as follows. The Falls Church DES estimates the number of single family dwelling accounts in the utility service area as 22,567 and the number of townhouse accounts as 7,064 as of December 1999, for a total of 29,631 single family household accounts. The number of households was reduced by 3.4% to account for the likely number of households in 1998, or 29,631 minus 1,007 equals 28,623. The reduction factor of 3.4 percent is estimated using growth patterns extracted from COG GIS data for the area. The number of 1998 multi-family households can thus be calculated by taking the total number of 1998 households in Falls Church from GIS sources, minus the number of estimated 1998 single family accounts, or 46,527 minus 28,623 equals 17,904 multi family units. The ratio of single family to multi family homes is 28,623 divided by 17,904, or 1.6.

The number of single family and multi-family households in the Vienna service area was calculated as follows. Given 9,056 households in the Vienna service areas in 1998, and assuming the same single family to multi family ratio of 1.6 as calculated for Falls Church, the number of single family homes in the Vienna service area is thus 5,573 and the number of multi-family homes is 3,483.

The number of 1998 single family households in the combined Falls Church and Vienna service areas is thus 28,623 plus5,573 equals 34,196; the number of multi family households is 17,904 plus 3,483 equals 21,387.

The combined Falls Church and Vienna service areas unit use for single-family residences is assumed to be the same as Arlington County DPW's unit use, or 185 gallons per day per household for a total water use of 6.3 mgd. The unit use for multi-family households is assumed to be the same as Arlington County DPW's unit use, or 150.3 gallons per household per day for a total water use of 3.2 mgd.

Determination of employee unit use factor

The number of 1998 employees in the combined service areas is 142,601, as based on a GIS overlay of the combined service areas with traffic analysis zones, extracting the 1995 and 2000 employment data and interpolating for 1998. The total water use for commercial water use was estimated by subtracting the unmetered and residential water uses from the total water purchased from WAD and FCWA. (16.3 mgd purchased from WAD plus 0.79 mgd purchased from FCWA minus 1.95 unaccounted, minus 6.33 mgd single family use, and minus 3.21 mgd multi family use which equals a net employee water use of 5.61 mgd. Given 142,601 employees in the combined service areas and a total water use of 5.61 mgd, a per employee unit use was derived of 39.4 gallons per employee per day.

WAD - Arlington County DPW

Unmetered water use

Arlington County DPW relies on water purchased from WAD. In 1998 Arlington County DPW purchased on average 27.6 mgd from WAD. The total water billed at Arlington County DPW in 1998 was 22.4 mgd. The unmetered/non-revenue water is the difference in the two figures, 5.2 mgd or 19%.

Billing records

Arlington County DPW uses residential, commercial, and apartment 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 1998 households in the Arlington County DPW's direct service area is 88,569 as based on a GIS overlay of Arlington County DPW's direct service area with traffic analysis zones, extracting the 1995 and 2000 household data and interpolating for 1998. Applying the dwelling unit ratio of 0.68 (number of single family residences divided by number of multi-family residences) to the number of 1998 households in the

FCWA service area yields 35,849 single family households and 52,720 multi-family households. The Arlington County DPW unit use for single-family residences is 185.0 gallons per day per household, as based on 6.63 mgd over 35,849 households. The Arlington County DPW unit use for multi-family households is 150.3 gallons per household per day as based on 7.92 mgd used by 52,720 multi-family households.

Determination of employee unit use factor

The total commercial water use for Arlington County DPW service area was 7.81 mgd in 1998. The number of 1998 employees in the Arlington County DPW service area is 159,934 as based on a GIS overlay of Arlington County DPW service area with traffic analysis zones, extracting the 1995 and 2000 employment data and interpolating for 1998. Given 159,934 employees in Arlington County DPW service area as calculated above, a per employee unit use was derived of 48.9 gallons per employee per day.

City of Rockville DPW

Unmetered water use

Rockville DPW relies on water withdrawn from the Potomac. Potomac diversions for the period calendar year 1998 were obtained from Rockville DPW. The total water diverted was initially reported as 5.4 mgd on average, but Rockville reports that the meter used to gage Potomac flow under-registered by 18%. A correction factor of 1.18 was applied to the 5.40 mgd average withdrawal to obtain a net Potomac withdrawal of 6.37 mgd. Unmetered/non-revenue water was assumed to be 10%, or 0.64 mgd.

Billing records

Billing records were not obtained from Rockville DPW.

Determination of multi-family and single family unit use factors

The number of 1998 households in the Rockville DPW's direct service area is 14,740 as based on a comparison of Rockville DPW's direct service area with traffic analysis zones. Each traffic analysis zone is associated with forecasts of population, households, and employees. GIS tools were used to estimate the 1995 and 2000 household data, which was interpolated for 1998. The estimate of the number of households was divided into categories of single family and multi family households by using a dwelling unit ratio. The dwelling unit ratio is simply the number of single family residences divided by number of multi-family residences. The estimate of dwelling unit ratio was obtained from the City of Rockville Community Planning and Development Services. Applying the dwelling unit ratio of 2.40 to the number of 1998 households in the Rockville DPW service area yields 10,405 single family households and 4,335 multi-family households. (For comparison, the City of Rockville DPW reports 10,179 single family accounts in its service area.) The Rockville DPW unit use for single-family residences is assumed to be the same as Arlington County DPW's unit use, or 185 gallons per day per household for a total water use of 1.9 mgd. The Rockville DPW unit use for multi-family households is assumed to be the same as Arlington County DPW's unit use, or 150.3 gallons per household per day for a total water use of 0.7 mgd.

Determination of employee unit use factor

The number of 1998 employees in the Rockville DPW's service area is 61,854 as based on a GIS overlay of Rockville DPW's service area with traffic analysis zones, extracting the 1995 and 2000 employment data and interpolating for 1998. The total water use for commercial water use was estimated by subtracting the residential and unmetered water uses from the total water withdrawn from the Potomac (6.37 – 1.9 – 0.7 – 0.64 = 3.1). Given 61,854 employees in Rockville DPW's service area as calculated above and a total water use of 2.9 mgd, a per employee unit use was derived of 51.1 gallons per employee per day.

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

Typical water use inside the home

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

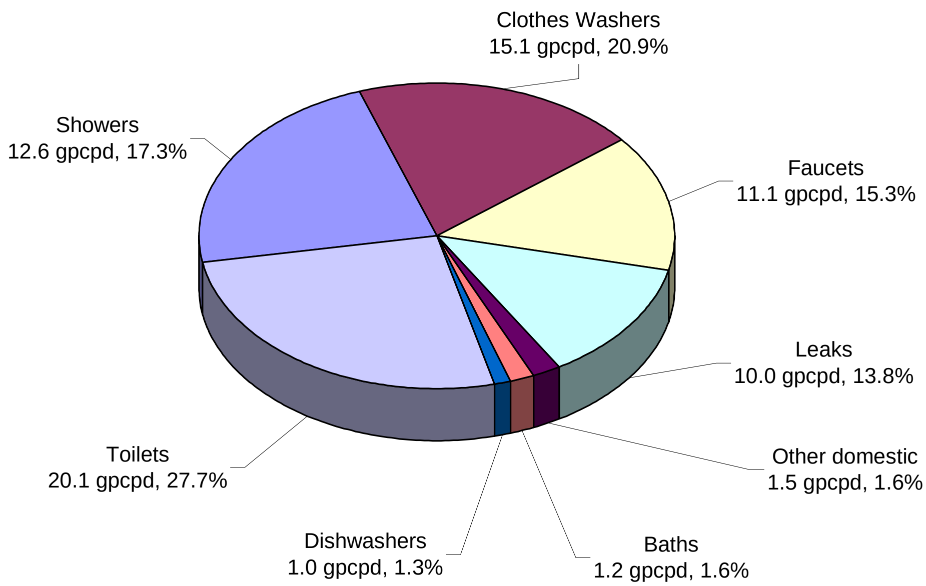

Figure 1: Typical per capita water use inside the single family home, without conservation measures (source: American Water Works Association "WaterWiser")

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Total water savings in the WMA

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

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Appendix L: Household and employee water use for each supplier

WSSC - Montgomery County

	1990	1995	2000	2005	2010	2015	2020
Households	259,669	276,856	291,301	310,446	330,018	350,744	364,736
Dwelling unit ratio	2.36	2.30	2.17	2.13	2.11	2.08	2.07
Single family	182,386	192,960	199,280	211,406	223,826	237,024	245,835
Multi-family	77,282	83,896	92,021	99,039	106,192	113,719	118,901
Employment	402,498	401,788	440,245	486,376	522,602	546,225	564,746
% Unaccounted	22.3%	22.3%	22.3%	22.3%	22.3%	22.3%	22.3%
Unit use (gpd)							
Single family	188.4	186.4	181.8	177.2	173.1	169.4	166.0
Multi-family	190.5	188.4	183.8	179.3	175.2	171.5	168.0
Employee	44.2	44.2	44.2	44.2	44.2	44.2	44.2
Water use (mgd)							
Single family	34.4	36.0	36.2	37.5	38.8	40.1	40.8
Multi-family	14.7	15.8	16.9	17.8	18.6	19.5	20.0
Employee	17.8	17.7	19.4	21.5	23.1	24.1	24.9
Unaccounted	14.9	15.5	16.2	17.1	18.0	18.7	19.2
Total water use	81.8	85.0	88.8	93.8	98.4	102.5	104.9

WSSC - Prince George's County

	1990	1995	2000	2005	2010	2015	2020
Households	243,451	262,864	277,154	293,153	308,862	325,393	341,132
Dwelling unit ratio	1.62	1.76	1.87	1.95	2.02	2.09	2.14
Single family	150,531	167,623	180,627	193,689	206,573	220,021	232,507
Multi-family	92,920	95,240	96,526	99,464	102,289	105,372	108,625
Employment	293,752	284,665	311,816	343,598	371,858	397,614	435,545
% Unaccounted	22.3%	22.3%	22.3%	22.3%	22.3%	22.3%	22.3%
Unit use (gpd)							
Single family	188.4	186.4	181.8	177.2	173.1	169.4	166.0
Multi-family	190.5	188.4	183.8	179.3	175.2	171.5	168.0
Employee	44.2	44.2	44.2	44.2	44.2	44.2	44.2
Water use (mgd)							
Single family	28.4	31.2	32.8	34.3	35.8	37.3	38.6
Multi-family	17.7	17.9	17.7	17.8	17.9	18.1	18.3
Employee	13.0	12.6	13.8	15.2	16.4	17.6	19.2
Unaccounted	13.2	13.8	14.4	15.0	15.7	16.3	17.0
Total water use	72.2	75.6	78.7	82.4	85.8	89.2	93.1
Total WSSC water use	154.0	160.6	167.5	176.2	184.2	191.7	197.9

Appendix L: Household and employee water use for each supplier

Rockville

	1990	1995	2000	2005	2010	2015	2020
Households	13,423	14,306	15,030	15,700	16,400	16,550	16,603
Dwelling unit ratio	3.15	3.19	2.37	2.28	2.20	2.13	2.08
Single family	10,188	10,892	10,576	10,914	11,276	11,265	11,217
Multi-family	3,234	3,414	4,454	4,786	5,124	5,285	5,385
Employment	59,595	56,674	65,308	69,214	72,036	74,432	75,820
% Unaccounted	11.0%	11.0%	11.0%	11.0%	11.0%	11.0%	11.0%
Unit use (gpd)							
Single family	191.7	189.6	185.0	180.5	176.4	172.6	169.2
Multi-family	156.9	154.9	150.3	145.7	141.6	137.9	134.5
Employee	51.1	51.1	51.1	51.1	51.1	51.1	51.1
Water use (mgd)							
Single family	2.0	2.1	2.0	2.0	2.0	1.9	1.9
Multi-family	0.5	0.5	0.7	0.7	0.7	0.7	0.7
Employee	3.0	2.9	3.3	3.5	3.7	3.8	3.9
Unaccounted	0.6	0.6	0.7	0.7	0.7	0.7	0.7
Total water use	6.1	6.1	6.6	6.9	7.1	7.2	7.2

FCWA to City of Falls Church, Vienna, and City of Fairfax

Water assumed sold by FCWA, mgd

	1990	1995	2000	2005	2010	2015	2020
Total sold to City of Falls Church	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total sold to Town of Vienna	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Total sold to City of Fairfax	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Appendix L: Household and employee water use for each supplier

FCWA - wholesale - Dulles

	1990	1995	2000	2005	2010	2015	2020
Households	0	3	0	0	0	0	0
Dwelling unit ratio	0	0	0	0	0	0	0
Single family	0	3	0	0	0	0	0
Multi-family	0	0	0	0	0	0	0
Employment	9,528	11,144	14,339	16,394	18,492	19,999	20,723
% Unaccounted	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%
Unit use (gpd)							
Single family	0	0	0	0	0	0	0
Multi-family	0	0	0	0	0	0	0
Employee	47.9	47.9	47.9	47.9	47.9	47.9	47.9
Water use (mgd)							
Single family	0.0	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	0.0
Employee	0.5	0.5	0.7	0.8	0.9	1.0	1.0
Unaccounted	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total water use	0.5	0.6	0.8	0.9	1.0	1.1	1.1

FCWA - wholesale - Fort Belvoir

	1990	1995	2000	2005	2010	2015	2020
Households	2,795	827	2,152	3,050	3,798	4,396	4,399
Dwelling unit ratio	3.19	3.20	3.19	3.21	3.24	3.27	3.29
Single family	2,128	630	1,638	2,326	2,903	3,366	3,373
Multi-family	667	197	514	724	895	1,030	1,026
Employment	18,619	23,014	24,880	28,655	32,020	35,623	39,038
% Unaccounted	13.1%	13.1%	13.1%	13.1%	13.1%	13.1%	13.1%
Unit use (gpd)							
Single family	225.2	223.2	218.6	214.0	209.9	206.2	202.8
Multi-family	198.5	196.4	191.8	187.3	183.2	179.5	176.0
Employee	50.1	50.1	50.1	50.1	50.1	50.1	50.1
Water use (mgd)							
Single family	0.5	0.1	0.4	0.5	0.6	0.7	0.7
Multi-family	0.1	0.0	0.1	0.1	0.2	0.2	0.2
Employee	0.9	1.2	1.2	1.4	1.6	1.8	2.0
Unaccounted	0.2	0.2	0.2	0.3	0.3	0.3	0.4
Total water use	1.7	1.5	1.9	2.3	2.7	3.0	3.2

Appendix L: Household and employee water use for each supplier

FCWA direct service area

	1990	1995	2000	2005	2010	2015	2020
Households	226,334	249,926	276,507	294,525	311,103	327,288	341,564
Dwelling unit ratio	3.19	3.20	3.19	3.21	3.24	3.27	3.29
Single family	172,316	190,420	210,444	224,641	237,762	250,600	261,899
Multi-family	54,018	59,506	66,063	69,884	73,341	76,688	79,665
Employment	263,152	287,552	348,041	393,823	425,655	453,709	473,944
% Unaccounted	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%
Unit use (gpd)							
Single family	225.2	223.2	218.6	214.0	209.9	206.2	202.8
Multi-family	198.5	196.4	191.8	187.3	183.2	179.5	176.0
Employee	45.8	45.8	45.8	45.8	45.8	45.8	45.8
Water use (mgd)							
Single family	38.8	42.5	46.0	48.1	49.9	51.7	53.1
Multi-family	10.7	11.7	12.7	13.1	13.4	13.8	14.0
Employee	12.1	13.2	16.0	18.1	19.5	20.8	21.7
Wholesale sales	32.4	39.3	43.8	50.5	58.4	65.7	71.2
Unaccounted	12.1	13.7	15.3	16.7	18.2	19.6	20.6
Total direct and unaccounted	73.7	81.1	89.9	95.9	101.1	105.8	109.5

FCWA - wholesale - Prince William County Service Authority

	1990	1995	2000	2005	2010	2015	2020
Households	42,609	50,079	57,418	69,072	80,213	91,712	97,823
Dwelling unit ratio	4.44	4.39	4.15	3.37	2.92	2.64	2.47
Single family	34,777	40,785	46,277	53,264	59,770	66,490	69,638
Multi-family	7,833	9,294	11,141	15,808	20,443	25,222	28,186
Employment	42,875	53,734	63,606	76,792	89,867	101,537	112,145
% Unaccounted	5.7%	5.7%	5.7%	5.7%	5.7%	5.7%	5.7%
Unit use (gpd)							
Single family	271.0	269.0	264.4	259.8	255.7	252.0	248.6
Multi-family	198.5	196.4	191.8	187.3	183.2	179.4	176.0
Employee	62.7	62.7	62.7	62.7	62.7	62.7	62.7
Water use (mgd)							
Single family	9.4	11.0	12.2	13.8	15.3	16.8	17.3
Multi-family	1.6	1.8	2.1	3.0	3.7	4.5	5.0
Employee	2.7	3.4	4.0	4.8	5.6	6.4	7.0
Unaccounted	0.8	0.9	1.0	1.2	1.4	1.6	1.7
Total water use	14.4	17.1	19.4	22.9	26.1	29.2	31.0
Total purchased from City of Manassas [a]	3.9	4.4	5	5	5	5	5
Total produced from PWSA wells	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total from FCWA	8.5	10.6	12.4	15.9	19.1	22.2	24.0

Notes: [a] Calculated for 1990 and 1995 as difference between total water use and that assumed produced from wells and purchased from FCWA. Assumed to be 5 mgd for 2000 and beyond (maximum per agreement).

Appendix L: Household and employee water use for each supplier

FCWA - wholesale - Town of Herndon

	1990	1995	2000	2005	2010	2015	2020
Households	5,472	6,092	7,034	7,935	8,820	9,704	10,508
Dwelling unit ratio	3.19	3.20	3.19	3.21	3.24	3.27	3.29
Single family	4,166	4,642	5,353	6,052	6,741	7,430	8,057
Multi-family	1,306	1,450	1,681	1,883	2,079	2,274	2,451
Employment	11,208	18,205	21,872	24,141	25,614	26,435	26,882
% Unaccounted	13.1%	13.1%	13.1%	13.1%	13.1%	13.1%	13.1%
Unit use (gpd)							
Single family	225.2	223.2	218.6	214.0	209.9	206.2	202.8
Multi-family	198.5	196.4	191.8	187.3	183.2	179.5	176.0
Employee	23.4	23.4	23.4	23.4	23.4	23.4	23.4
Water use (mgd)							
Single family	0.9	1.0	1.2	1.3	1.4	1.5	1.6
Multi-family	0.3	0.3	0.3	0.4	0.4	0.4	0.4
Employee	0.3	0.4	0.5	0.6	0.6	0.6	0.6
Unaccounted	0.2	0.2	0.3	0.3	0.3	0.3	0.4
Total water use	1.7	2.0	2.3	2.5	2.7	2.9	3.0

FCWA - wholesale - Lorton

	1990	1995	2000	2005	2010	2015	2020
Households	7	1	1	1	1	1	1
Dwelling unit ratio	0	0	0	0	0	0	0
Single family	7	0	0	0	0	0	0
Multi-family	0	1	1	1	1	1	1
Employment	6,582	8,512	934	167	618	505	528
% Unaccounted	13.5%	13.5%	13.5%	13.5%	13.5%	13.5%	13.5%
Unit use (gpd)							
Single family	225.2	223.2	218.6	214.0	209.9	206.2	202.8
Multi-family	0	0	0	0	0	0	0
Employee[a]	120.9	120.9	120.9	45.8	45.8	45.8	45.8
Water use (mgd)							
Single family	0.0	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	0.0
Employee	0.8	1.0	0.1	0.0	0.0	0.0	0.0
Unaccounted	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Total water use	0.90	1.17	0.13	0.01	0.03	0.03	0.03

Note: [a] employee unit use rate is changed post-2000 to reflect closing of Lorton prison.

Appendix L: Household and employee water use for each supplier

FCWA - wholesale - VAWC - Alexandria

	1990	1995	2000	2005	2010	2015	2020
Households	53,280	56,421	61,522	63,554	65,542	67,197	68,609
Dwelling unit ratio	0.45	0.45	0.45	0.43	0.41	0.40	0.39
Single family	16,535	17,510	19,172	19,172	19,172	19,172	19,172
Multi-family	36,745	38,911	42,350	44,382	46,370	48,025	49,437
Employment	92,209	91,942	98,552	105,783	110,369	113,232	115,890
% Unaccounted	4.4%	4.4%	4.4%	4.4%	4.4%	4.4%	4.4%
Unit use (gpd)							
Single family	211.0	209.0	204.4	199.9	195.7	192.0	188.6
Multi-family	187.2	185.1	180.5	176.0	171.9	168.1	164.7
Employee	45.8	45.8	45.8	45.8	45.8	45.8	45.8
Water use (mgd)							
Single family	3.5	3.7	3.9	3.8	3.8	3.7	3.6
Multi-family	6.9	7.2	7.6	7.8	8.0	8.1	8.1
Employee	4.2	4.2	4.5	4.8	5.1	5.2	5.3
Unaccounted	0.6	0.7	0.7	0.7	0.7	0.7	0.8
Total water use	15.2	15.7	16.8	17.2	17.5	17.7	17.8

FCWA - wholesale - VAWC - Dale City

	1990	1995	2000	2005	2010	2015	2020
Households	14,030	16,594	17,840	17,955	18,982	19,102	19,102
Dwelling unit ratio	10.93	10.93	10.93	10.56	10.22	9.92	9.64
Single family	12,853	15,202	16,344	16,401	17,290	17,352	17,306
Multi-family	1,177	1,392	1,496	1,554	1,692	1,750	1,796
Employment	6,117	8,022	8,740	9,386	9,776	9,991	10,126
% Unaccounted	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%	7.9%
Unit use (gpd)							
Single family	206.6	204.5	199.9	195.4	191.3	187.6	184.1
Multi-family	198.5	196.4	191.8	187.3	183.2	179.5	176.0
Employee	88.2	88.2	88.2	88.2	88.2	88.2	88.2
Water use (mgd)							
Single family	2.7	3.1	3.3	3.2	3.3	3.3	3.2
Multi-family	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Employee	0.5	0.7	0.8	0.8	0.9	0.9	0.9
Unaccounted	0.3	0.3	0.3	0.3	0.4	0.3	0.3
Total water use	3.7	4.4	4.7	4.7	4.8	4.8	4.7

Appendix L: Household and employee water use for each supplier

FCWA - wholesale - Loudoun County Sanitation Authority

	1990	1995	2000	2005	2010	2015	2020
Households	16,756	22,359	33,409	49,479	63,318	77,148	90,693
Dwelling unit ratio	5.23	5.27	4.63	3.74	3.37	3.17	3.06
Single family	14,066	18,793	27,470	39,035	48,830	58,646	68,381
Multi-family	2,690	3,566	5,939	10,444	14,488	18,502	22,312
Employment	16,803	22,438	34,220	49,502	62,339	74,715	87,694
% Unaccounted	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%
Unit use (gpd)							
Single family	282.0	280.0	275.4	270.8	266.7	263.0	259.6
Multi-family	165.4	163.4	158.8	154.2	150.1	146.4	143.0
Employee	29.8	29.8	29.8	29.8	29.8	29.8	29.8
Water use (mgd)							
Single family	4.0	5.3	7.6	10.6	13.0	15.4	17.7
Multi-family	0.4	0.6	0.9	1.6	2.2	2.7	3.2
Employee	0.5	0.7	1.0	1.5	1.9	2.2	2.6
Unaccounted	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Total water use	5.1	6.7	9.8	14.1	17.6	20.9	24.2
Total supplied by City of Fairfax	5.1	5.0	5.0	7.0	7.0	7.0	7.0
Total supplied by FCWA	0.1	3.3	4.8	7.1	10.6	13.9	17.2

Aqueduct-WASA-District of Columbia

	1990	1995	2000	2005	2010	2015	2020
Households	249,634	232,097	221,796	224,291	235,401	247,204	256,305
Dwelling unit ratio	0.66	0.66	0.71	0.71	0.71	0.71	0.71
Single family	99,252	92,280	92,091	93,127	97,740	102,640	106,419
Multi-family	150,382	139,817	129,705	131,164	137,661	144,564	149,886
Employment	747,316	701,902	678,014	698,105	725,713	754,426	776,804
% Unaccounted	34.2%	34.2%	34.2%	34.2%	34.2%	34.2%	34.2%
Unit use (gpd)							
Single family	311.0	309.0	304.4	299.8	295.7	292.0	288.6
Multi-family	311.0	309.0	304.4	299.8	295.7	292.0	288.6
Employee	43.8	43.8	43.8	43.8	43.8	43.8	43.8
Water use (mgd)							
Single family	30.9	28.5	28.0	27.9	28.9	30.0	30.7
Multi-family	46.8	43.2	39.5	39.3	40.7	42.2	43.3
Employee	32.8	30.8	29.7	30.6	31.8	33.1	34.0
Unaccounted	37.7	35.0	33.2	33.4	34.6	36.0	36.9
Total water use	148.1	137.5	130.4	131.3	136.1	141.2	144.9

Appendix L: Household and employee water use for each supplier

Aqueduct - WASA - Pentagon, Arlington cemetery, Fort Myer

	1990	1995	2000	2005	2010	2015	2020
Households	245	252	251	250	249	249	249
Dwelling unit ratio	0.67	0.67	0.67	0.61	0.57	0.54	0.51
Single family	98	101	100	95	90	87	85
Multi-family	147	151	151	155	159	162	164
Employment	33,753	29,184	29,184	30,464	30,464	30,464	30,464
% Unaccounted	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%
Unit use (gpd)							
Single family	191.7	189.6	185.0	180.5	176.4	172.6	169.2
Multi-family	156.9	154.9	150.3	145.7	141.6	137.9	134.5
Employee	50.1	50.1	50.1	50.1	50.1	50.1	50.1
Water use (mgd)							
Single family	0.0	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	0.0
Employee	1.7	1.5	1.5	1.5	1.5	1.5	1.5
Unaccounted	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total water use	2.0	1.7	1.7	1.8	1.8	1.8	1.8

Aqueduct - WASA - National

	1990	1995	2000	2005	2010	2015	2020
Households	0	0	0	0	0	0	0
Dwelling unit ratio	0	0	0	0	0	0	0
Single family	0	0	0	0	0	0	0
Multi-family	0	0	0	0	0	0	0
Employment	11,038	9,938	9,938	9,938	9,938	9,938	9,938
% Unaccounted	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%
Unit use (gpd)							
Single family	0	0	0	0	0	0	0
Multi-family	0	0	0	0	0	0	0
Employee	47.9	47.9	47.9	47.9	47.9	47.9	47.9
Water use (mgd)							
Single family	0	0	0	0	0	0	0
Multi-family	0	0	0	0	0	0	0
Employee	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Unaccounted	0	0	0	0	0	0	0
Total water use	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Total (Pentagon, Arl. Cem., Fort Myer and Reagan National)	2.6	2.2	2.2	2.3	2.3	2.3	2.3

Appendix L: Household and employee water use for each supplier

Aqueduct-Arlington DPW

	1990	1995	2000	2005	2010	2015	2020
Households	78,275	86,646	89,851	93,754	97,150	100,513	103,865
Dwelling unit ratio	0.70	0.70	0.67	0.61	0.57	0.54	0.51
Single family	32,231	35,678	35,898	35,484	35,277	35,284	35,287
Multi-family	46,044	50,968	53,953	58,270	61,873	65,229	68,578
Employment	138,336	156,671	162,109	170,063	196,550	215,764	234,979
% Unaccounted	22.9%	22.9%	22.9%	22.9%	22.9%	22.9%	22.9%
Unit use (gpd)							
Single family	191.7	189.6	185.0	180.5	176.4	172.6	169.2
Multi-family	156.9	154.9	150.3	145.7	141.6	137.9	134.5
Employee	48.9	48.9	48.9	48.9	48.9	48.9	48.9
Water use (mgd)							
Single family	6.2	6.8	6.6	6.4	6.2	6.1	6.0
Multi-family	7.2	7.9	8.1	8.5	8.8	9.0	9.2
Employee	6.8	7.7	7.9	8.3	9.6	10.5	11.5
Unaccounted	4.6	5.1	5.2	5.3	5.6	5.9	6.1
Total water use	24.8	27.4	27.9	28.5	30.2	31.5	32.8

Aqueduct - Falls Church DPW and Vienna DPW - Falls Church and Vienna

	1990	1995	2000	2005	2010	2015	2020
Households	50,706	52,625	57,555	60,334	63,048	65,687	68,048
Dwelling unit ratio	1.40	1.40	1.60	1.60	1.60	1.60	1.60
Single family	29,578	30,698	35,418	37,128	38,799	40,423	41,875
Multi-family	21,127	21,927	22,137	23,205	24,249	25,264	26,172
Employment	113,356	116,439	127,257	138,803	156,687	151,144	155,783
% Unaccounted	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%	12.9%
Unit use (gpd)							
Single family	191.7	189.6	185.0	180.5	176.4	172.6	169.2
Multi-family	156.9	154.9	150.3	145.7	141.6	137.9	134.5
Employee	45.7	45.7	45.7	45.7	45.7	45.7	45.7
Water use (mgd)							
Single family	5.7	5.8	6.6	6.7	6.8	7.0	7.1
Multi-family	3.3	3.4	3.3	3.4	3.4	3.5	3.5
Employee	5.2	5.3	5.8	6.3	7.2	6.9	7.1
Unaccounted	1.8	1.9	2.0	2.1	2.2	2.2	2.3
Total water use	16.0	16.4	17.7	18.5	19.7	19.6	20.0
FCWA supplied	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Net WAD supplied	15.2	15.6	16.9	17.7	18.9	18.8	19.2

Appendix M. Disaggregated forecast of demand for the Aqueduct

	2000	2005	2010	2015	2020
Average annual production, mgd	178	180	188	194	199
Mean monthly demand					
January	170	172	179	185	190
February	165	168	175	180	185
March	166	168	175	181	186
April	167	170	177	183	188
May	172	175	182	188	193
June	183	186	193	200	206
July	204	207	216	223	229
August	203	206	214	222	228
September	188	191	199	205	211
October	178	181	188	194	200
November	168	171	178	184	189
December	165	168	175	181	186
Mean Peak 1-day production, mgd					
January	199	202	211	218	224
February	193	196	204	211	217
March	192	195	203	210	215
April	197	199	208	215	221
May	209	212	220	228	234
June	220	223	233	240	247
July	247	250	261	269	277
August	239	242	252	261	268
September	212	215	224	231	238
October	206	209	218	225	231
November	190	192	200	207	213
December	190	193	201	208	214
Mean Peak 7-day production, mgd					
January	180	183	190	197	202
February	173	176	183	189	195
March	175	177	185	191	196
April	175	178	185	191	197
May	190	193	201	208	214
June	202	205	214	221	227
July	223	226	236	244	250
August	221	224	234	241	248
September	199	201	210	217	223
October	187	190	198	205	210
November	178	180	188	194	200
December	174	177	184	190	196
Average July 1 - October 31 production, mgd	197	200	208	215	221

Appendix N. Disaggregated forecast of demand for FCWA

	2000	2005	2010	2015	2020
Average annual production, mgd	135	148	161	173	182
Mean monthly demand					
January	117	128	139	149	157
February	114	125	136	146	154
March	116	127	138	149	157
April	126	138	150	161	170
May	138	151	164	176	185
June	153	167	182	196	206
July	166	181	197	212	223
August	169	185	202	217	228
September	149	163	177	190	200
October	131	144	156	168	177
November	123	135	146	157	166
December	119	130	142	152	160
Mean Peak 1-day production, mgd					
January	128	140	152	164	173
February	123	135	147	158	166
March	130	143	155	167	176
April	141	154	168	180	190
May	173	189	206	222	233
June	186	204	222	239	251
July	199	218	237	255	268
August	200	218	238	255	269
September	185	203	221	237	250
October	145	159	173	186	196
November	134	147	160	172	181
December	132	145	157	169	178
Mean Peak 7-day production, mgd					
January	120	132	143	154	162
February	117	128	139	149	157
March	122	134	145	156	165
April	133	145	158	170	179
May	160	175	190	204	215
June	173	189	206	221	233
July	189	207	226	243	255
August	186	204	221	238	251
September	169	185	202	217	228
October	137	151	164	176	185
November	127	139	151	162	171
December	123	135	147	158	166
Average July 1 - October 31 production, mgd	153	167	182	195	206

Appendix O. Disaggregated forecast of demand for the WSSC

	2000	2005	2010	2015	2020
Average annual production, mgd	168	176	184	192	198
Mean monthly demand					
January	158	167	174	181	187
February	155	164	171	178	184
March	155	163	170	177	183
April	160	168	176	183	189
May	171	179	188	195	202
June	181	191	199	207	214
July	192	202	211	219	226
August	188	198	207	215	222
September	176	185	194	202	208
October	163	171	179	186	192
November	157	165	172	179	185
December	154	162	169	176	182
Mean Peak 1-day production, mgd					
January	178	187	195	203	210
February	168	176	184	192	198
March	174	183	191	199	205
April	175	184	193	201	207
May	201	211	221	230	237
June	212	223	234	243	251
July	221	233	243	253	261
August	221	232	243	253	261
September	199	209	219	228	235
October	180	189	198	206	213
November	170	179	187	195	201
December	170	179	187	195	201
Mean Peak 7-day production, mgd					
January	165	174	182	189	195
February	159	168	175	182	188
March	160	169	176	184	190
April	167	176	184	191	198
May	186	196	205	213	220
June	197	207	217	226	233
July	210	221	231	240	248
August	207	217	227	236	244
September	189	199	208	217	224
October	168	176	184	192	198
November	160	168	176	183	189
December	160	168	176	183	189
Average July 1 - October 31 production, mgd	183	193	201	210	216

Appendix P. Disaggregated forecast of demand for CO-OP

	2000	2005	2010	2015	2020
Average annual production, mgd	480	504	533	558	579
Mean monthly demand					
January	445	468	494	518	537
February	436	457	483	507	526
March	437	459	485	509	528
April	453	476	503	527	547
May	480	504	533	558	579
June	517	542	573	601	623
July	561	589	623	653	677
August	559	587	620	650	675
September	513	538	569	596	618
October	472	496	524	549	570
November	448	470	497	521	541
December	439	460	487	510	529
Mean Peak 1-day production, mgd					
January	487	511	541	567	588
February	465	489	516	541	561
March	468	492	520	545	565
April	503	528	558	585	607
May	562	590	624	654	678
June	603	633	669	701	727
July	648	680	719	754	782
August	649	681	720	755	783
September	575	604	638	669	694
October	518	544	575	603	626
November	476	500	529	554	575
December	480	504	532	558	579
Mean Peak 7-day production, mgd					
January	463	486	513	538	558
February	447	469	496	520	539
March	452	475	502	526	546
April	473	497	525	550	571
May	534	560	592	621	644
June	560	588	622	652	676
July	617	648	685	718	745
August	610	640	677	710	736
September	552	579	612	642	666
October	490	514	544	570	591
November	461	484	512	537	557
December	454	476	504	528	548
Average July 1 - October 31 production, mgd					
	531	557	589	617	640

Appendix Q: Meeting notes for public information meetings of October 29, 1999 and January 31, 2000

INTERSTATE COMMISSION ON THE POTOMAC RIVER BASIN
SECTION FOR COOPERATIVE WATER SUPPLY OPERATIONS ON THE POTOMAC

Year 2000 20-Year Water Demand Forecast and Resource Availability Analysis

Tasks

1. Conduct water demand forecast to the year 2020
    - Determine forecast model (unit use, MAIN, etc.)
    - Define present and future distribution areas (and where they get water, eg Loudoun)
    - Obtain forecast data for independent variables
    - Calculate a range of scenario forecasts
        - Consider alternative population & other independent variables forecasts
        - Consider alternative conservation (passive/program) methods (incl. Pricing)
        - Consider unaccounted water
        - Consider climate change impacts on water demand
    - Other

2. Conduct water resource availability analysis
    - Complete CO-OP regional resources ops model
    - Consider increasing return flows from STPs
    - Consider siltation impact on reservoir storage
    - Consider water quality operations at JRL, Savage, L'l Seneca, and Patuxent
    - Consider Little Falls environmental flow-by
    - Consider climate change impacts on hydrology
    - HEP generagion at Dams 4&5
    - C&O Canal watering (metro section)
    - Other

3. Evaluate the adequacy of available water supplies
    - Results of the CO-OP regional water resources operations model
    - Consider alternate resource limitations (emergency storage vs. 40% full)
    - Other

4. Conduct public out-reach
    - Invite comments from those with diverse relevant interests
    - Consider obtaining technical advice/review

5. Prepare report

INTERSTATE COMMISSION ON THE POTOMAC RIVER BASIN
SECTION FOR COOPERATIVE WATER SUPPLY OPERATIONS ON THE POTOMAC

Year 2000 20-Year Water Demand Forecast and Resource Availability Analysis
for the Washington metropolitan area

Information Meeting

October 29, 1999

1:00 p.m.

Agenda:

1. Welcome and introductions
2. Purpose of meeting
3. Motivation for, and scope of, the study
4. Forecast model
5. Developmentof water demand forecasts
6. Determination of available resources
7. Discussion
8. Next meeting: issues, date

Notes from October 29, 1999 Meeting

Interstate Commission on the Potomac River Basin
Section for Cooperative Water Supply Operations on the Potomac
November 4, 1999
2000 Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area

1. Purpose of meeting

- To describe approach of the demand forecast and resource availability analysis
- Seek comments on methods and approach to the tasks

2. Motivation for, and scope of, the study

The motivation and scope for the study derives from the Low Flow Allocation Agreement (LFAA) which states, "In April 1990 and in April of each fifth year thereafter ... the Aqueduct, the Authority, the Commission and the District shall review and evaluate the adequacy of the then available water supplies to meet the water demands in the Washington Metropolitan Area which may then be expected to occur during the succeeding twenty year period." The parties to the LFAA have directed ICPRB's CO-OP Section to conduct the 20-year water demand forecast and resource availability analysis.
Study scheduled for presentation at the April 2000 meeting of the parties to the LFAA.

3. Forecast model

"Simple" model selected, where water use "D" is a function of unit use coefficients "C" multiplied by independent variables "V." (See attached graphic.) A range of coefficients will be used to reflect different scenarios. A range of alternate values of independent variables will be estimated using regionally available forecasts of households and employment zones by geographic region.

4. First major task: development of water demand forecast

Analysis will be conducted using GIS tools. This information will be linked to spreadsheets that can be easily updated as new forecasts of population become available. A series of subtasks make up the water demand forecast:

4.A. Define present and future distribution areas for utilities

- Each utility and its wholesale customers will be contacted and asked to define the current service area.
- Future service areas are somewhat trickier to define. We are asking the question what will service areas look like in 20 years. To answer this question, we anticipate using existing comprehensive plans including any water and sewer specific plans, for example as are available in Montgomery and Prince George's counties. Because their planning horizons in some cases may be as short as 10 years, we anticipate going out to appropriate county planning agencies to ask the question what might service areas look like in 20 years.

4.B Obtain forecast data for independent variables

- We are lucky in this region to have detailed and comprehensive estimates of future population as developed by COG. These estimates are developed for individual small zones in the metro area called COG analysis zones.
- Each zone is associated with forecasts of households and employees. The employee category is broken down into categories of retail, industrial and office employees. COG has already supplied us with the GIS layer of COG analysis zones. (See attached graphic).
- The analysis will be conducted by overlaying the projected 2020 service areas onto the COG analysis zones, and calculating future demand by simply multiplying the forecasts of households and employees by appropriate coefficients of water use.

4.C Calculate a range of scenario forecasts

To consider a range of potential coefficients, each representing different assumptions. The goal is to report the range of the results in order to evalutate the sensitivity of the results to different assumptions. Scenarios include:

- *Alternative population forecasts* if they are available, i.e., COG "low, medium and high" population estimates.
- *Alternative conservation measures* and how water use might be affected. This will be based on a review of currently available reports and literature to determine how similar jurisdictions have cost effectively reduced demand using least cost planning or "total water management" approaches.
- *Effects of the 1992 Federal Energy Policy Act.* Assume some replacement rate of existing stock of older fixtures due to remodeling as well as construction of new homes, and assess the effect on per capita water use.
- *Demand reduction during drought (restrictions).* Demand for water increases during summertime, this is primarily due to outdoor watering. Summertime demand factors can be significantly reduced during times of drought if voluntary and mandatory restriction measures are implemented as the region heads into a serious drought. This means that projected demand in time of drought will be less than the demand that would otherwise have occurred in a normal year. This serves to push back the time that water shortages would occur in case of a drought of record.
- *Unaccounted for water.* We must assess the withdrawals from the point of view of what the river sees, which is not reported production but actual withdrawals.
- *Climate change impacts on water demand.* Consider results of a prior study specific to Potomac basin.
- Possibly other forecast scenarios.

5. Second major task: conduct water resource availability analysis

Analysis will be conducted using a simulation model of daily streamflow and regional resources developed at ICPRB. This simulation model utilizes established operating rules to allocate raw water resources. It relies on a water balance at each reservoir to account for reservoir inflows, releases, and storage. Historical daily inflows going back to 1927 have been developed for use with this model. Analysis will be conducted using projected demands through the year 2020 with the historical inflows and Potomac flows, and existing reservoir resources. This simulation includes analysis of how the current system would be affected by the severe historic droughts

including the so-called droughts of record from 1930-31 and again in 1966. The operations model is user friendly and can be easily adapted to incorporate new scenarios.
A series of scenarios will be considered:

- *Increasing return flows from sewage treatment plants (STPs).* There are several STPs that discharge treated water upstream of the water intakes. These discharges will be estimated for future years and incorporated into the model as available for further use. STPs include a WSSC plant in the Seneca watershed, the UOSA plant in the Occoquan watershed, and the planned Loudoun County Sanitation Authority STP on Broad Run.
- *Siltation impact on reservoir storage.* Siltation effects on reservoir storage have been estimated, and the estimated future capacities of the reservoirs will be used when evaluating the resources.
- *Water quality operations at JRL, Savage, L'l Seneca, and Patuxent.* There are other uses of upstream Jennings Randolph and Savage reservoirs that affect the natural flow of the Potomac River. The model will reflect how these operations will affect flow downstream in Washington.
- *Little Falls environmental flow-by*. The model will include provision for meeting the recommended environmental flows at DC.
- *Climate change impacts on hydrology.* Consider results of a prior study specific to Potomac basin.
- *Hydroelectric power generation at Dams 4 & 5.* These are low-head dams in the Potomac. We were concerned about potential diurnal fluctuation in river flow during low flow periods. However, there was no effect on water management or resource availability during the drought of 1999.
- *C&O Canal watering (metro section).* Some water is diverted into the C&O Canal for the stretch above Great Falls to below Little Falls, and must be considered as a net water demand in models (see also comments section 6).
- *Jennings Randolph efficiency of releases.* Some provision in the analysis will be made for the inefficiency of Jennings Randolph releases. The travel time of a Jennings Randolph release is 9 days to the water supply intakes. Releases are made based on expected flow in the river, which in turn can be influenced by local precipitation. Weather forecasts over a nine day period are not perfect, so like the 1999 drought there will be some periods when a release is made for anticipated conditions that do not materialize because of rainfall during the nine days that the release is on its way to Washington. (See also attached graphic.)
- *Alternate resource limitations (emergency storage vs. 40% full).* The planning endpoint should not assume that the reservoirs would be drawn down to empty. Some storage should be reserved for emergency uses so that there is the capability of meeting demands for fire protection and hospitals.
- *Possibly other resource scenarios.*

6. Issues raised by attendees

Several points were raised during the following discussion as outlined below.

- Dann Sklarew, SAIC. Question, how would a range for the results be determined, via deterministic or statistical methods? Response: Deterministic streamflow model to be used to evaluate different scenarios. Results to be based on ranges that are associated with best estimates of independent variables. For example, population might be associated with low and high estimates, for instance +/- 10%.

- Pavi Spoon, Prince George's County DER. Variability of coefficients for the future unit use in the model should be addressed. Response: Coefficients will vary to incorporate future scenarios, e.g., conservation options, effects of Federal Energy Policy Act of 1992.
- Janet Norman, USFWS. Interview utilities as well as county planners for future service areas. Response: Yes.
- Mike Crean, WSSC. How were area boundaries determined for the COG Analysis Zones? Response from Normand Goulet, that they are originally based on census zones. More information obtained via phone interview with Paul DesJardin, November 1, 1999: 30 years ago first based on census tracts, and have since changed dramatically. In 1993 they were based on collections of census blocks that most closely approximated the previous sets of zones, albeit with additional subdivisions and splits. Current COG Analysis Zones are also split by major transportation facilities, physical boundaries like rivers, and by political boundaries.
- Roger Kilgore, Greenhorne & O'Mara, Inc. Question, how would consensus be determined for these scenarios? Response: The range of coefficients chosen for the analysis will likely address multiple potential values, thus probably obviating the need for consensus.
- Bill Werrick, USCOE Institute for Water Resources. How will this study be used? What policy decisions will be made, and how will the study's recommendations be implemented? Response: The study is answers the simple question, "How will the current system of reservoirs and river meet demands of the year 2020?" No policy decisions or recommendations will be made in this study, e.g., that future resources be built or that future conservation scenarios be implemented. Instead, this study is intended to provide background for making future policy decisions with regard to the provision of water to the region.
- Tim Coughlin, Loudoun County Sanitation Authority. Will reclaimed water and treated effluent be included in the resource availability portion of study? Response: Yes, there are three sources of treated effluent that plan to be included so far, UOSA in the Occoquan watershed, LCSA planned plant in Broad Run, and WSSC's plant in the Seneca watershed.
- Jennifer Melton, WAD. Will minimum flow releases from all reservoirs be taken into account in the system model? Response: Yes.
- David Binning, Fairfax County Water Authority. Comment. The bathymetric study of the Occoquan will be ready in summer of 2000.
- Neal Fitzpatrick, Audubon Naturalist Society. How will climate change be incorporated into resource availability analysis? Response: Prior studies specific to Potomac basin to be looked at and incorporated into analysis as appropriate.
- Janet Norman, USFWS. 1981 environmental flow study needs to be updated. Instream needs can be assessed using currently available literature. Shouldn't current study incorporate an estimate of a future flowby into the analysis? Response: There are no studies specific to the Potomac since 1981 that indicate other values that could be used. Limited scope of this study, which answers specific question of current resources and future demands. More comprehensive study necessary to establish flowby, which likely will be driven by biological needs and science and water availability, which is a different

scope of study. The modeling and hydrology tools developed for the 2000 demand study are easily updated for inclusion in a broader scope study to examine the environmental flow issue.

- Tim Hirrel, WSSC. What would flow have been without withdrawals on the JRR release graphs? Response: about 400-500 mgd higher.
- Jack Frost, USDA-Natural Resource Conservation Service. Local reservoir flexibility to cover deficits in a Jennings Randolph release? Response: there is some flexibility, but the local reservoirs are already close to their maximum withdrawal levels during times of drought.
- Matthew Pajerowski, MDE. Comment: Water that is diverted into the C&O Canal should not be counted as a net demand during times of drought as there is a regional agreement in place that allows for this diversion to be stopped.
- Mike Crean, WSSC. What are the upstream consumptive uses in the basin? Response: This question has never been quantitatively answered. We have until now assumed that most upstream water withdrawn returns to the river. The "Basinwide Demand Study" is scheduled for completion in September of 2000, so there will be much more known about upstream water users and the amount of water that is returned to the Potomac after completion of that study.
- Dann Sklarew, SAIC. Will any new work be conducted looking at specific aquifers and their yields as a part of this study? Response: No, this study will incorporate information from existing studies only, furthermore, the groundwater/surface water connnection is not being modeled in this study.
- David Sobers, URS Greiner/ Woodward Clyde. Will sabotage/accidental spill be incorporated into the study? Response: No; however, the system of resources could be modeled under assumptions that one or more reservoirs or river intakes are not available. Gary Fisher, USGS, commented that FEMA considers water supply security issues.
- Matthew Pajerowski, MDE.   Will ICPRB conduct a Source Water Assessment (SWA) for area? The states and DC will be responsible for developing assessments.

7. Future meeting: issues, date.

There will be a January meeting to present data and methods selected and invite further comments.

Agenda for 2020 metropolitan Washington water demand study
2nd Public information meeting, January 31, 2000

ICPRB CO-OP section

I. Introduction: two pronged approach to the study:

A. **Demands**: Emphasis on estimating the metropolitan Washington area water supply requirements (demands) in year 2020.

B. **Resource analysis**: To see how current system of rivers and reservoirs functions under estimated future demands.

II. Study geographic focus:

A. Study applies to CO-OP member water suppliers and wholesale customers.

III. Study Method and status report

A. **Demands:** Develop estimate of future demand. Subtasks include:

1) define current and future service areas for each utility,
2) overlay current and future service areas with COG traffic analysis zones,
3) estimate current and future numbers of households and employees in each distinct utility service area as based on COG traffic analysis zones,
4) contact planners from each jurisdiction to further break down numbers of households into single family versus multi-family categories,
5) develop estimates of current per capita water use,
6) estimate future per capita water use as to incorporate effects of *Energy Policy Act of 1992*,
7) determine seasonal water use patterns,
8) apply per capita water use to future population estimates to develop an estimate of future summertime water use,
9) bracket estimate using high and low estimates of population as provided by MWCOG,
10) consider potential climate change effects on demands, and
11) consider an enhanced conservation alternative.

B. **Resource analysis:** Compare future demands to existing water system's ability to meet demands. Use current system operations to determine available water resources. Resource considerations include:

1) climate change effects on resources,
2) emergency demand reduction strategies including voluntary and mandatory restrictions and their impacts on demands,
3) siltation impact on reservoir storage,
4) increasing return flows from upstream wastewater treatment plants,
5) C&O canal watering,
6) current Little Falls environmental flow rates.
7) Reservoirs not drawn down to zero.

C. **Results:** A range of demand forecasts will be compared with the available resources.

IV. Timeline

A. The results of the study will be communicated at the April meeting of the signatories to the Low Flow Allocation Agreement and at the following website: http://www.potomacriver.org. A report will be published at ICPRB and available for the printing cost.

V. Issues raised at prior meeting:

A. **Flowby**: A change in the environmental flow rate would likely affect the results of the resource availability analysis. There are proposals to revisit the 1981 study. (Maryland House Bill 64, *Task Force to Study the Minimum Flow Levels in the Potomac River.)*

The ICPRB model has been constructed so that it can easily simulate future changes to the environmental flow rates. However, it is not clear at this time what those flow rates might be and therefore impossible to model at this time. As a general rule of thumb, for each 100 mgd that the summertime minimum flow is increased during the period from June through November, the upstream storage required would be 1 bg to augment flow for 10 days.

B. **Alternative resource limitations.** For planning purposes, the reservoirs will be considered "empty" when they reach emergency storage levels. Emergency storage is defined by the utilities as that storage below which the utility would not withdraw water except in an emergency. To fully understand the limitations of the resources, model runs will also be conducted that draw the reservoirs to empty.

C. **Efficiency of Jennings Randolph Release.** Strategies for developing better Jennings Randolph efficiency will be devised using the simulation model.

D. **Others.**

Notes from January 31, 2000 Public Information Meeting at Rockville, MD
Washington Metropolitan Area Water Demand Forecast to 2020

Interstate Commission on the Potomac River Basin
Section for Cooperative Water Supply Operations on the Potomac
February 1, 2000

1. Welcome and introductions

2. What, where, how, when of the project.

3. Handouts: outline of study 'sub-tasks,' maps and data tables

4. Questions and answers:
    - a. Partially served traffic analysis zones were divided not just by % area served, but also by density of roads, building footprints, etc.
    - b. Year 2020 service areas were derived from communication with planning personnel as well as from comprehensive plans.
    - c. Industrial water use is converted to employee water use because it is the number of employees for which forecasts are available.
    - d. The forecast will take into account water supplied outside the direct service area of WSSC.
    - e. Although the MWCOG population forecasts are the most detailed for the region, they will be compared with data from other available sources.
    - f. Population forecasts used in previous water demand studies will be compared with current forecasts.
    - g. The employee per capita water use will incorporate the difference between day and night water use in the District of Columbia.
    - h. There is a fairly high degree of confidence in the effectiveness of low flow fixtures based on the results of the AWWARF study results.
    - i. The inter-annual variability of weather and other factors makes it difficult to determine if the ratio of peak day to annual average water use shows a trend over the available record.
    - j. Peak and annual average data are missing for a couple of years in the 1980s because they were not readily available.
    - k. The effects of both long-term conservation measures and short term restrictions will be explored.
    - l. Water loss between plant and customer meter will be incorporated in the category of unaccounted or unmetered water.
    - m. We are working with the suppliers to refine data from billing records to develop good per capita water use factors.
    - n. The resource model to be used is an object oriented model build upon the operating rules of a prior Fortran model. Changes will include nine-day travel time from JRR and release efficiency.

o. Increases in future sewage flow will come from sewage flow forecasts – not based on water supply forecasts.
p. Although it is intuitive that up stream population increases will also affect the available water resource, any such impacts will not be determined for this study.
q. Policy positions such as “new resources will be needed when ... “ will not be part of the study conclusions.
r. The forecast demands will be tested against all years of flow record (not just the “worst” year) to determine the adequacy of resources.
s. The MWCOG TAZs will be used as the most disaggregate geographical unit for forecasting.
t. Rates of reservoir siltation will be derived from past studies of the issues for individual reservoirs.
u. Although it is intuitive that up stream changes in land use may affect the base flow and runoff components of river flow, any such impacts will not be determined for this study.

5. It was agreed that this would be the last information meeting for this study; however, any further ideas would be welcome on an individual basis.

6. Attendees were thanked, and the meeting was adjourned at approximately 2:30 pm.