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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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.

1 Study objective and background

1.1 Objective

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 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 Interstate Commission on the Potomac River Basin (ICPRB) to conduct the required review and evaluation of demands and supplies. This study is the third of three such reports prepared by ICPRB (Holmes and Steiner, 1990; Mullusky et al., 1996) to reflect changing growth and water use patterns.

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:

- 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.

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.

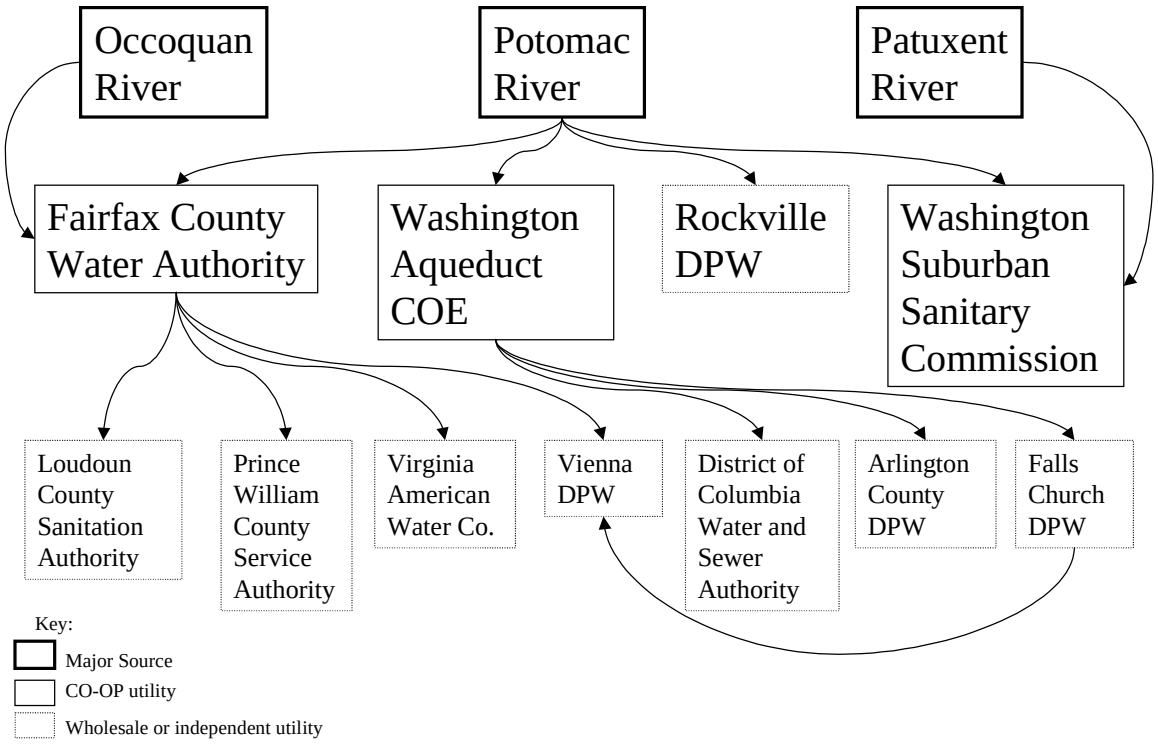

Figure 2-1: Schematic of study area and resources

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.

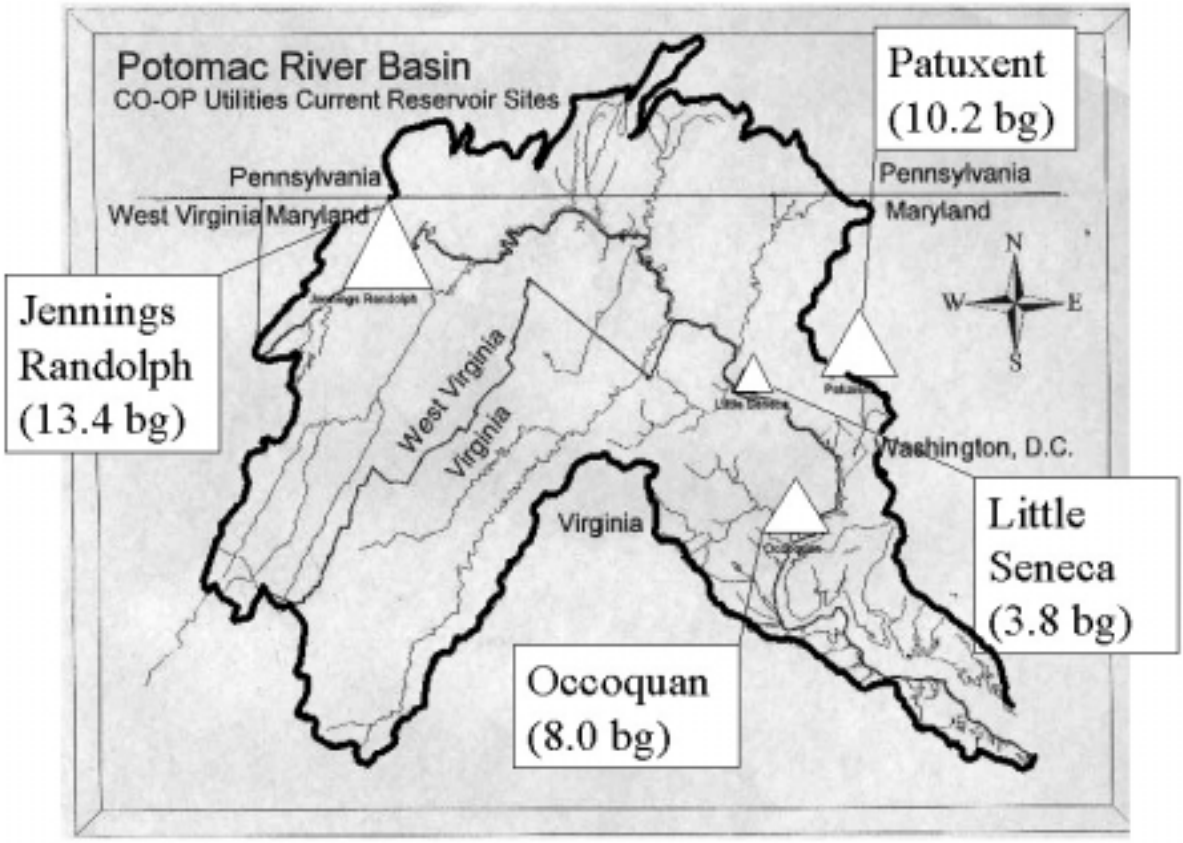

Figure 2-2: CO-OP utility reservoir sites

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).

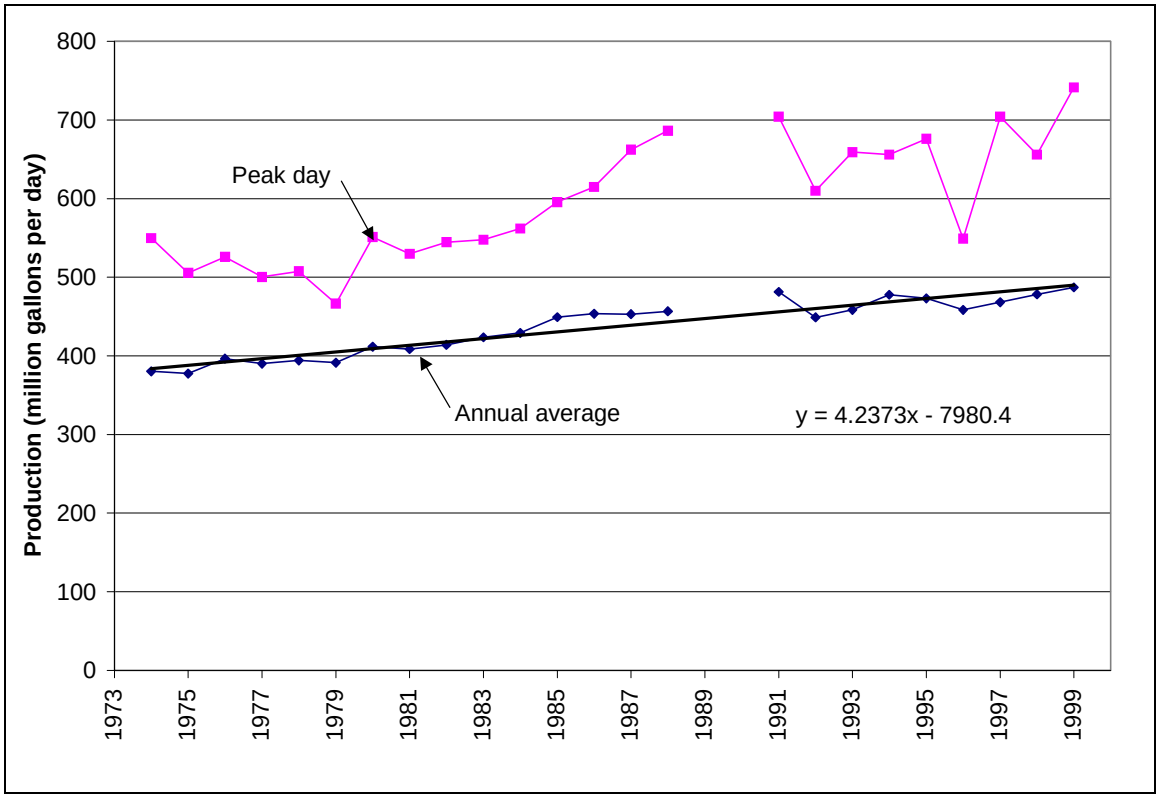

Figure 2-3: WSSC, the Aqueduct, and FCWA annual average and peak day demand

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.

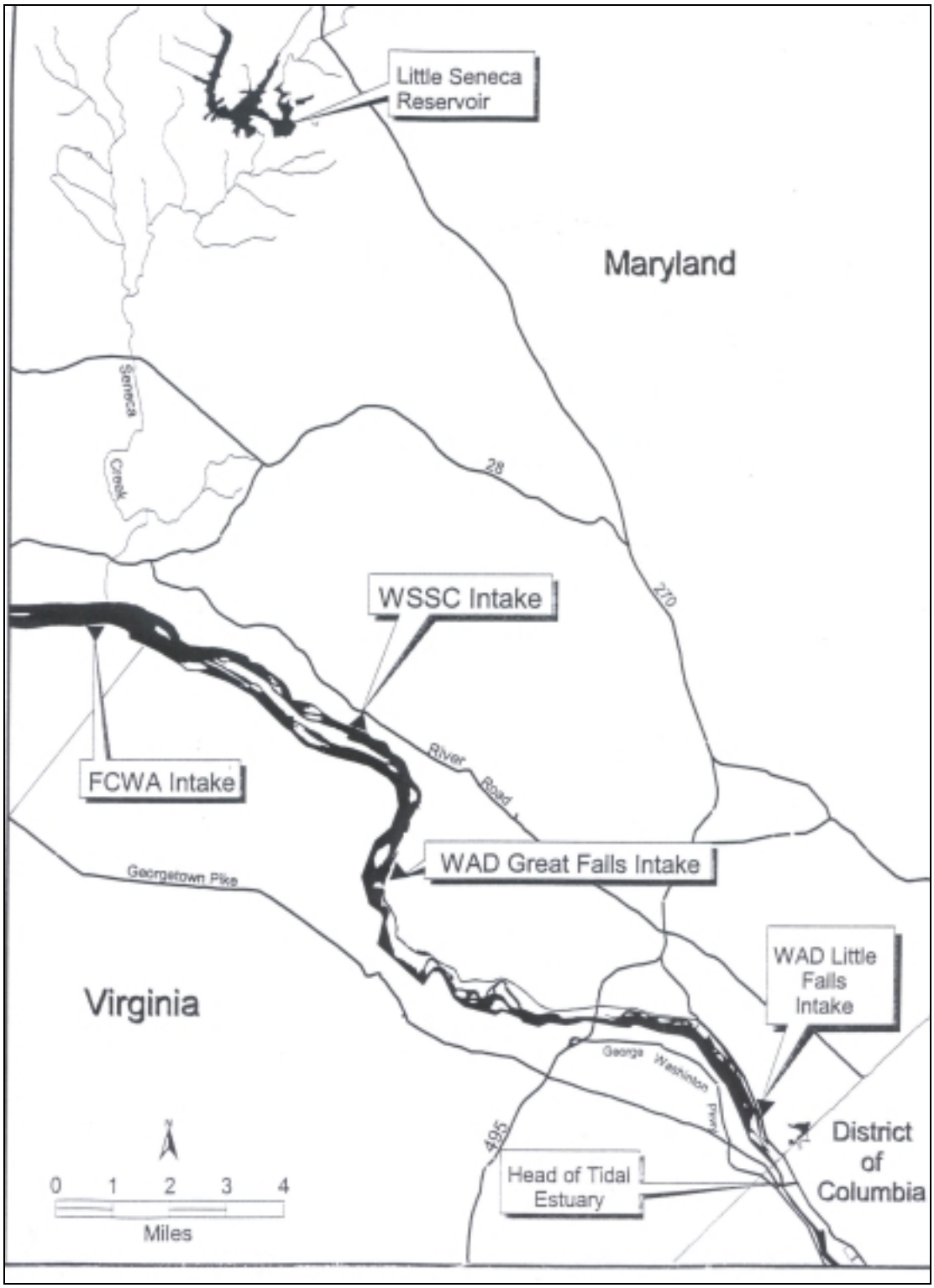

Figure 2-4: CO-OP system Potomac intakes

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.

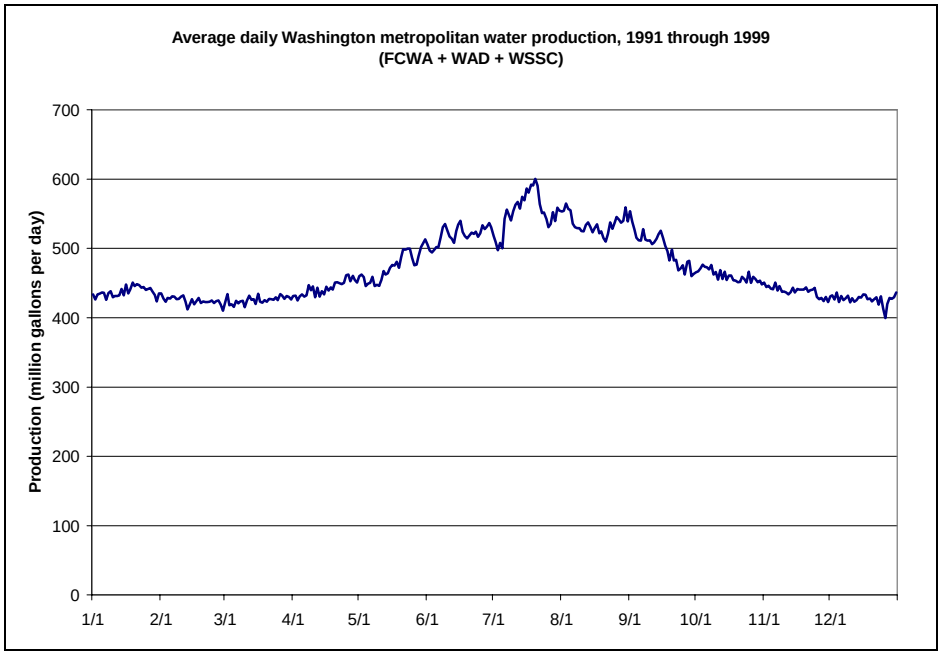

Figure 3-1: Average daily WMA production, 1991-1999 (FCWA + Aqueduct + WSSC)

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.

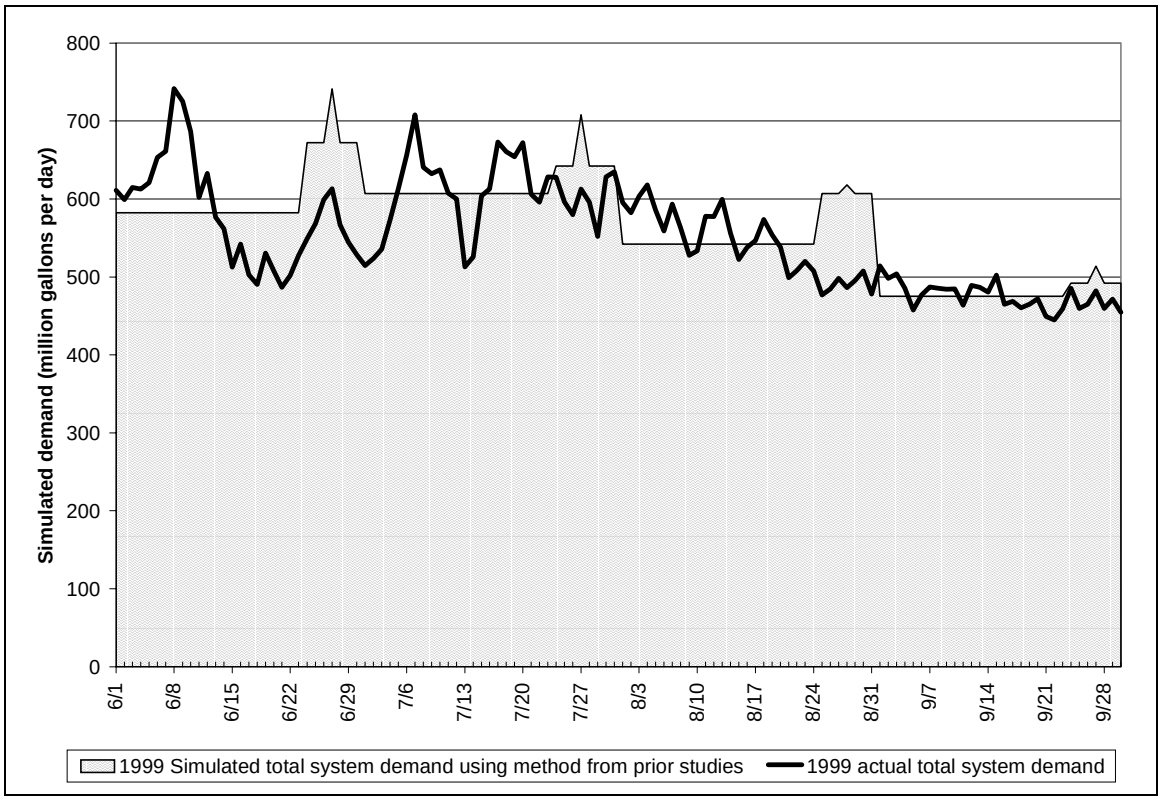

Figure 3-2: Example of simulated demand pattern as used in prior studies as compared to actual system demand

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.

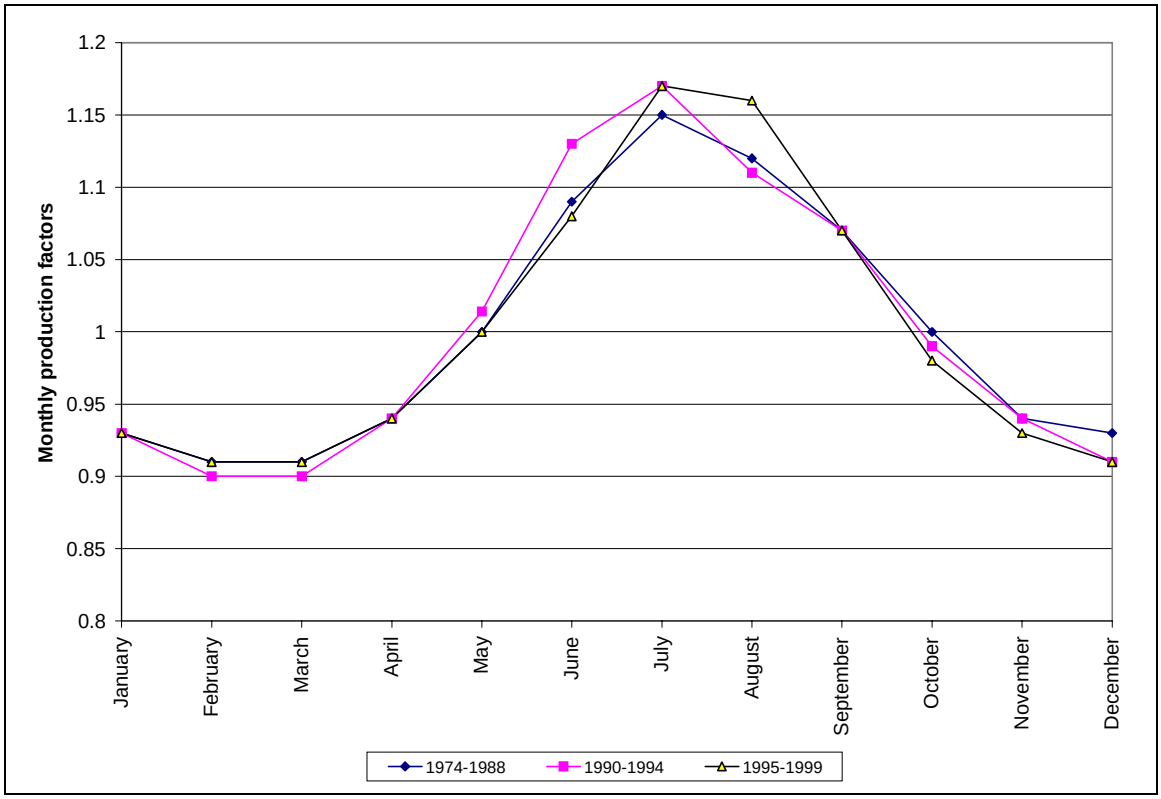

Figure 3-3: System monthly production factors, past and present

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.

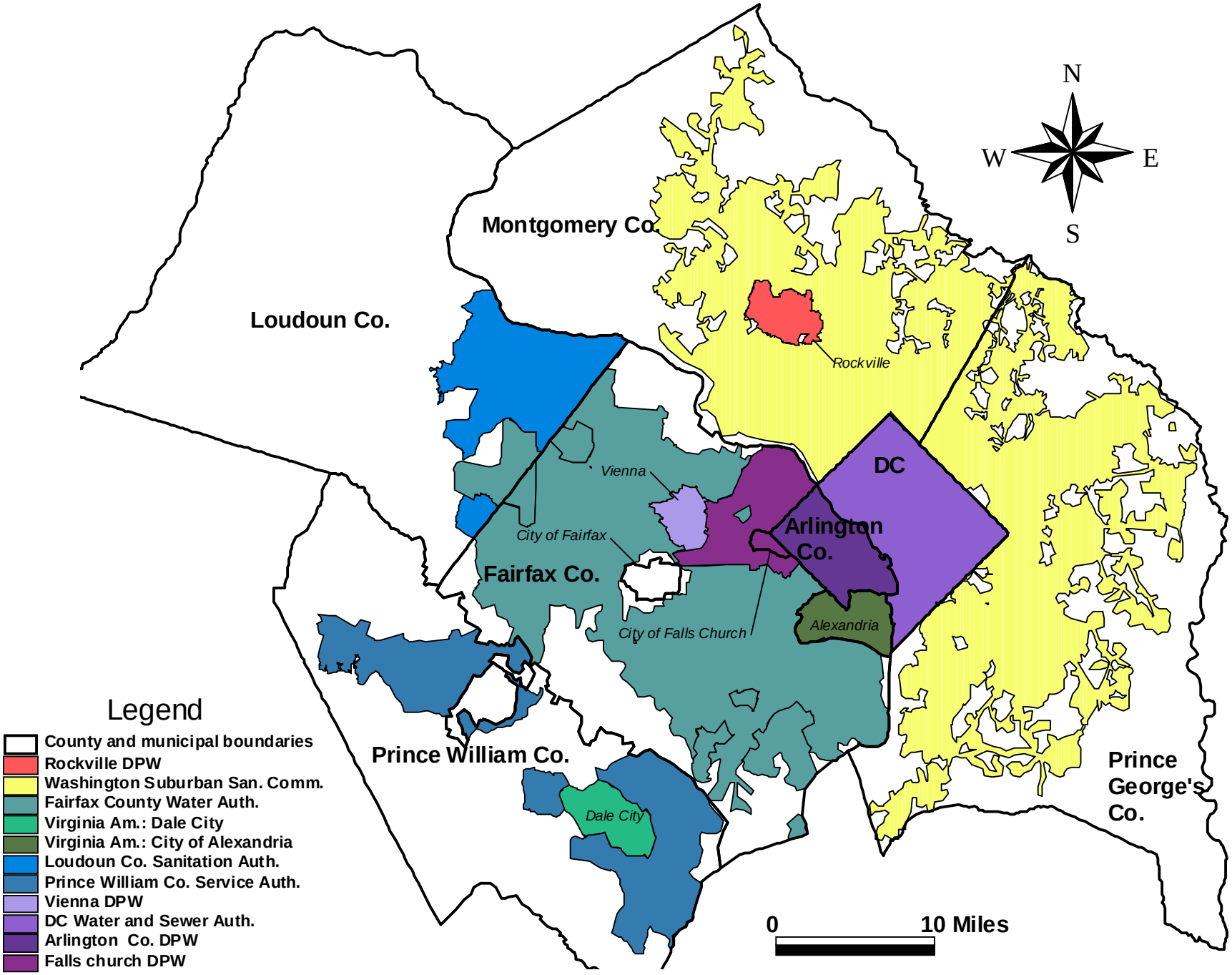

Figure 4-1: Water supplier service areas in the Washington metropolitan area, year 2000

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.

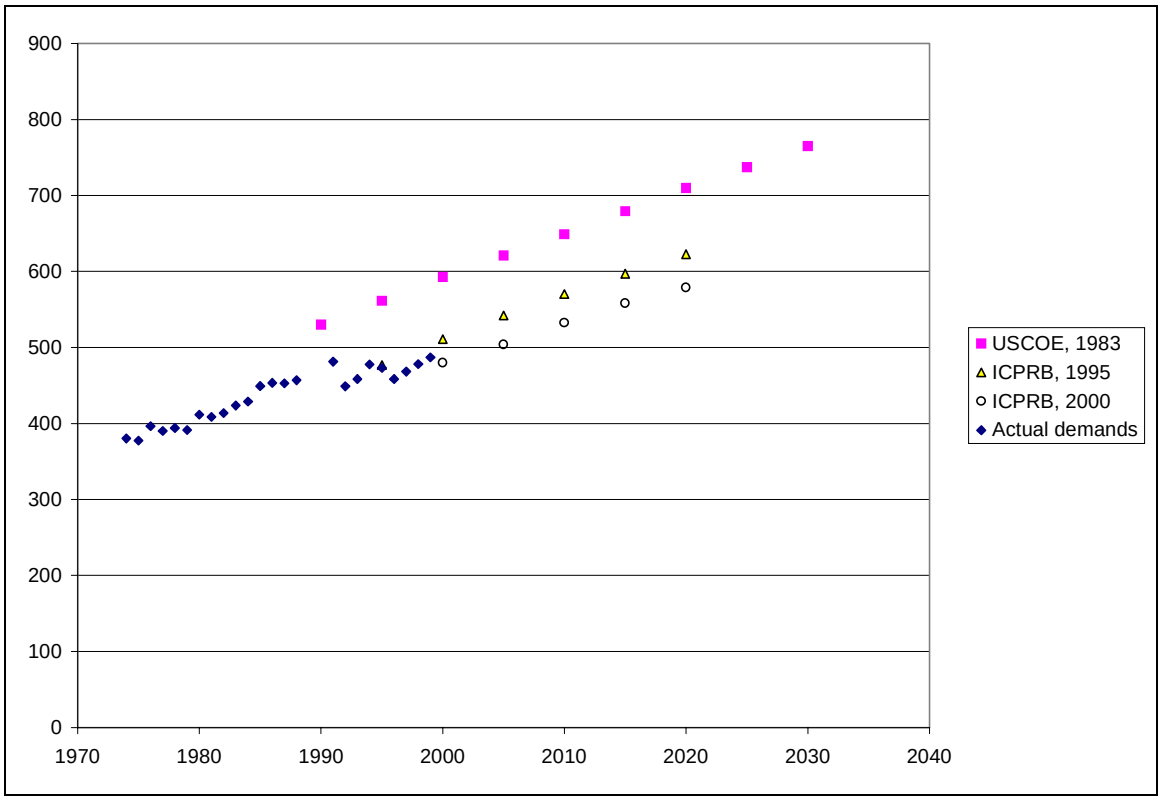

Figure 5-1: Comparison with forecasts from earlier studies

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.

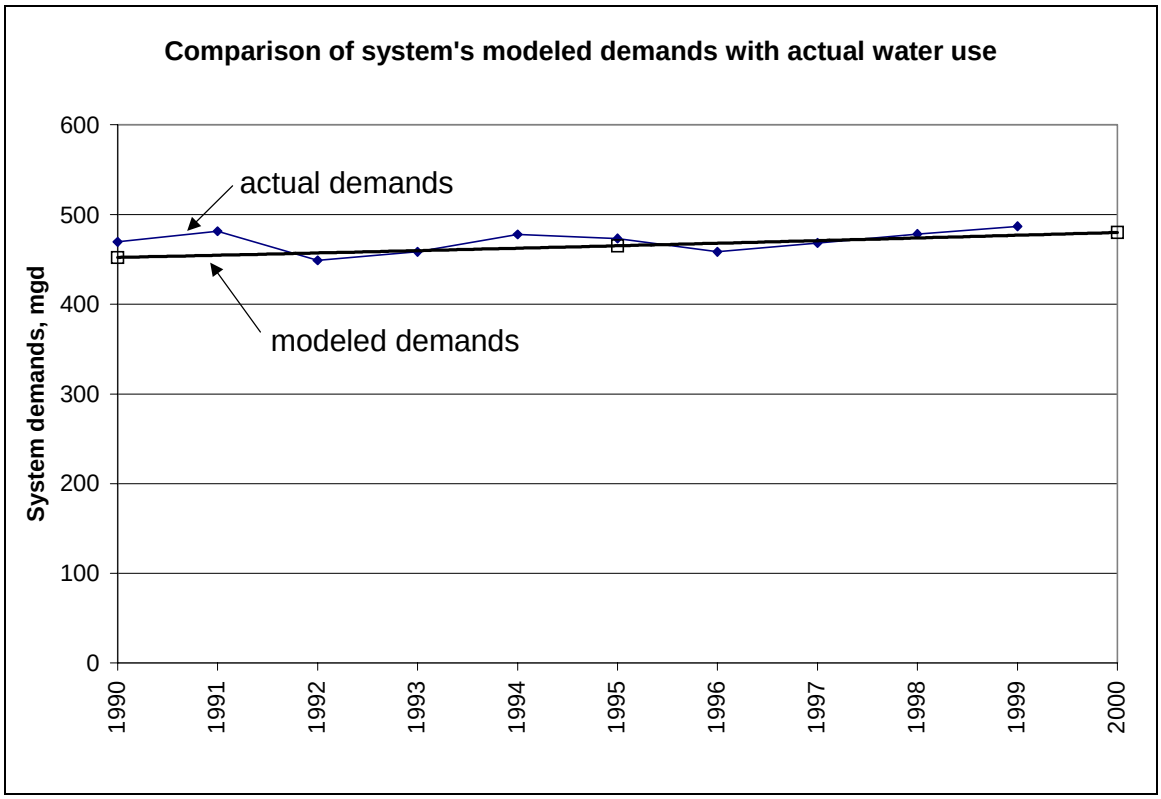

Figure 5-2: Calculated (modeled) and actual demands for the CO-OP utilities

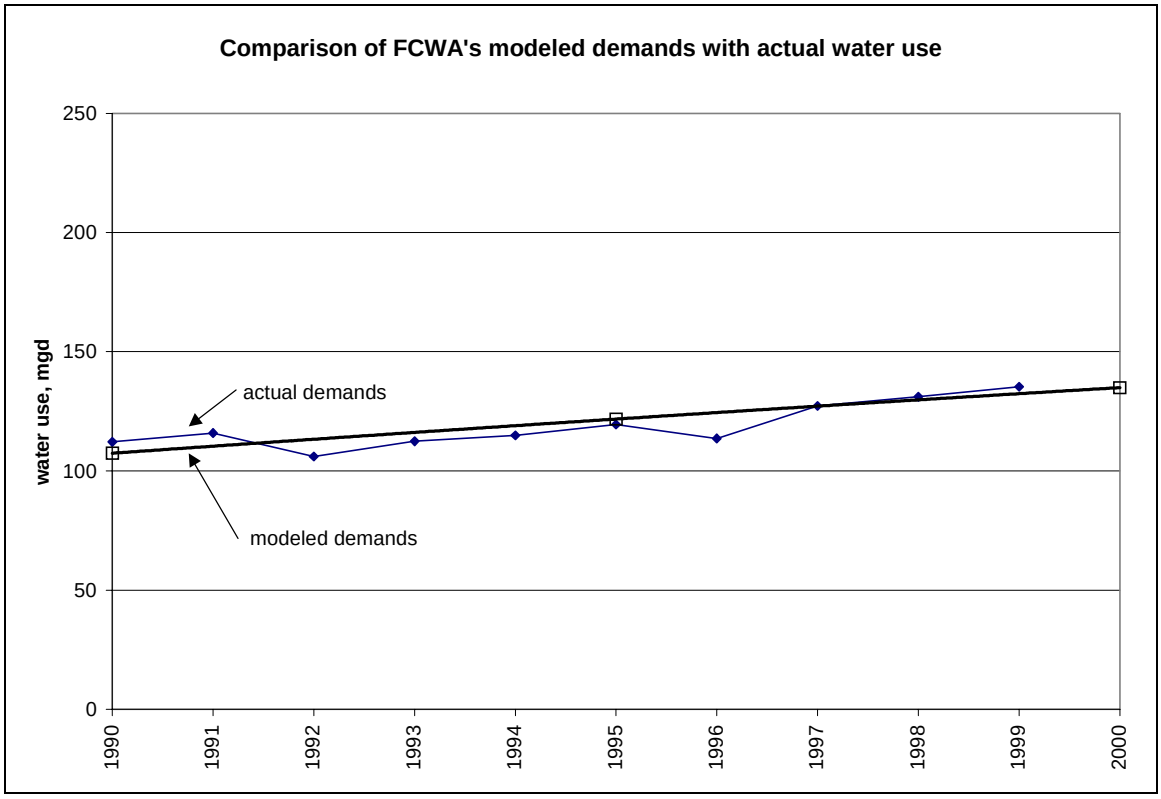

Figure 5-3: Calculated (modeled) and actual demands for FCWA

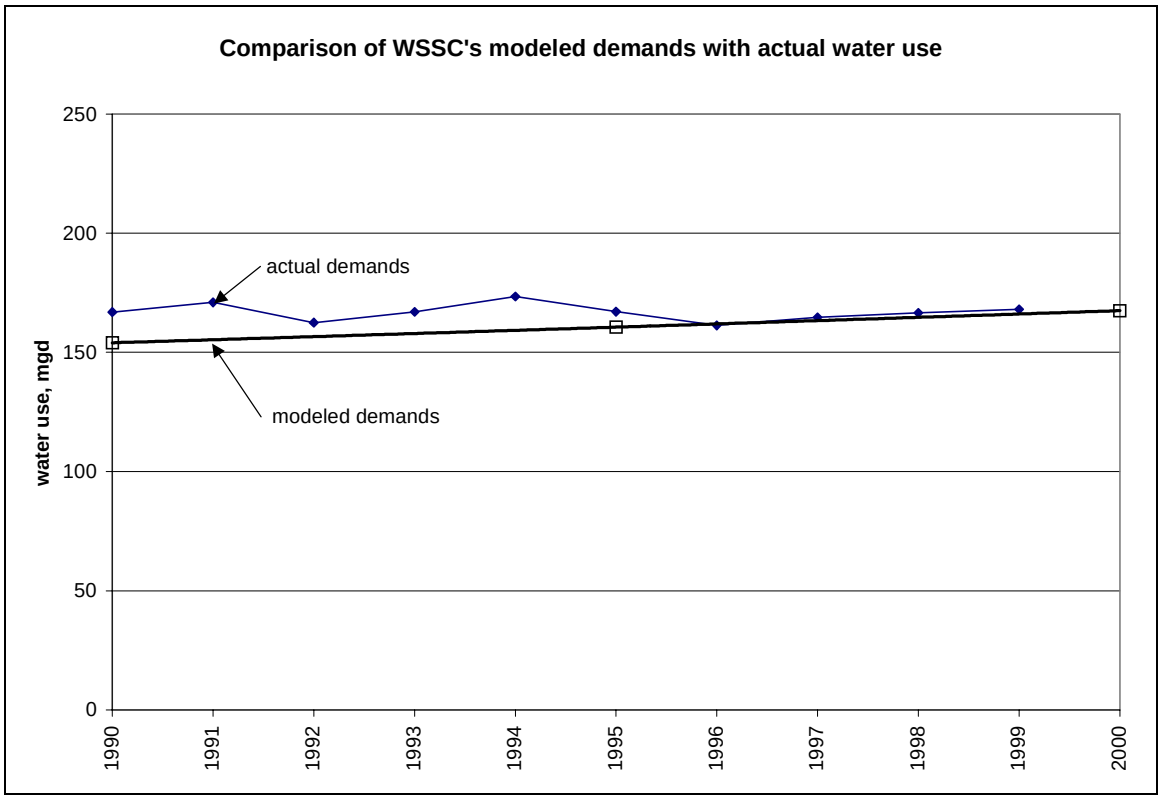

Figure 5-4: Calculated (modeled) and actual demands for WSSC

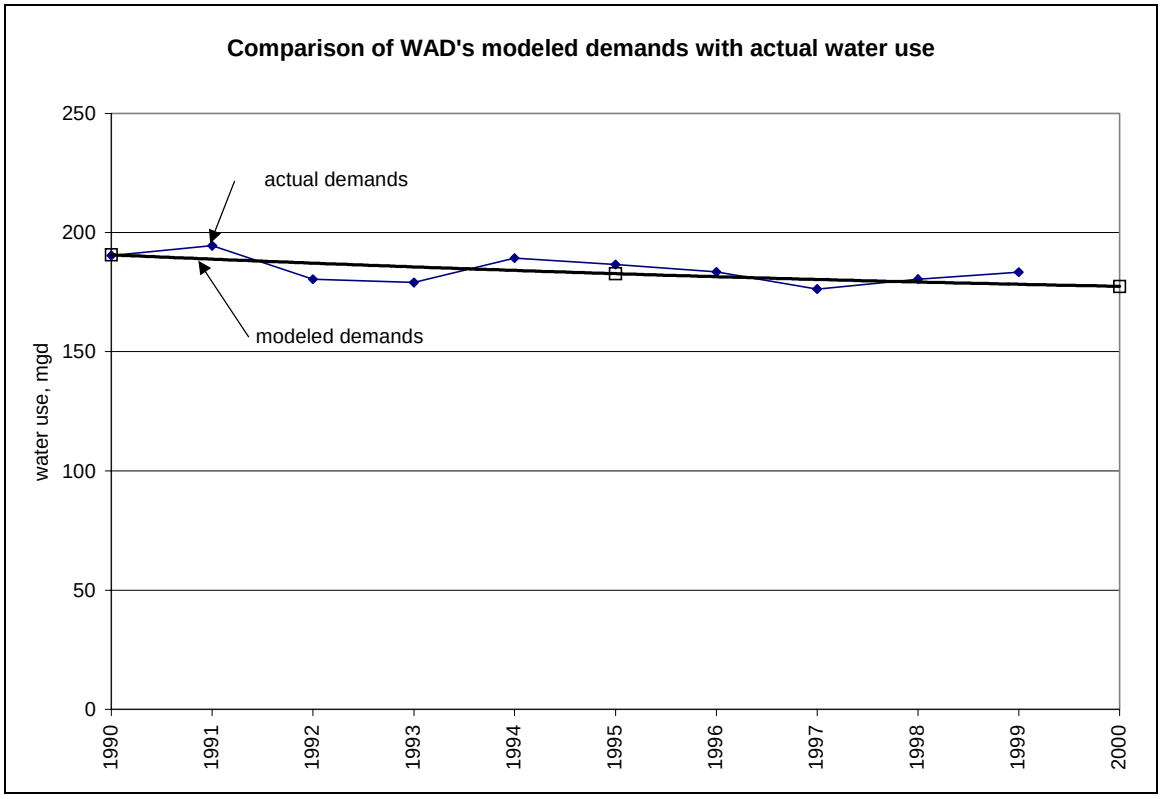

Figure 5-5: Calculated (modeled) and actual demands for the Aqueduct

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.

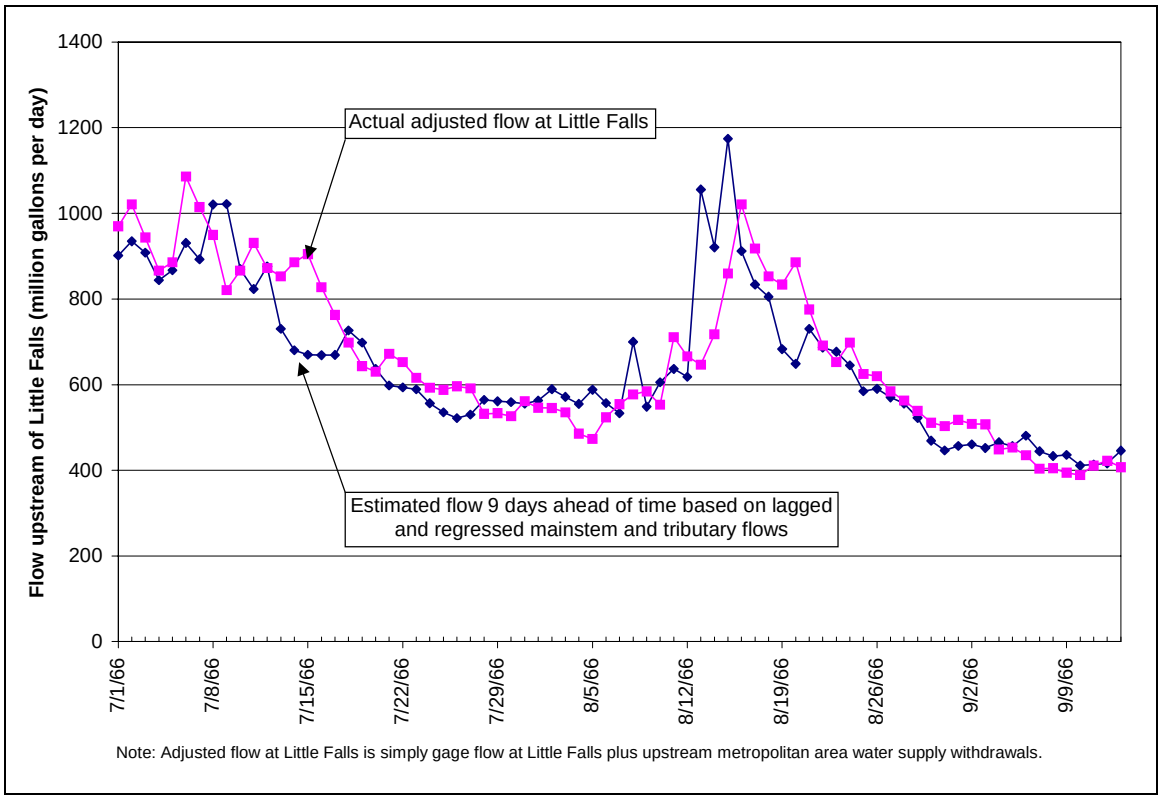

Figure 6-1: Comparison of predicted and actual flows upstream of Little Falls

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.

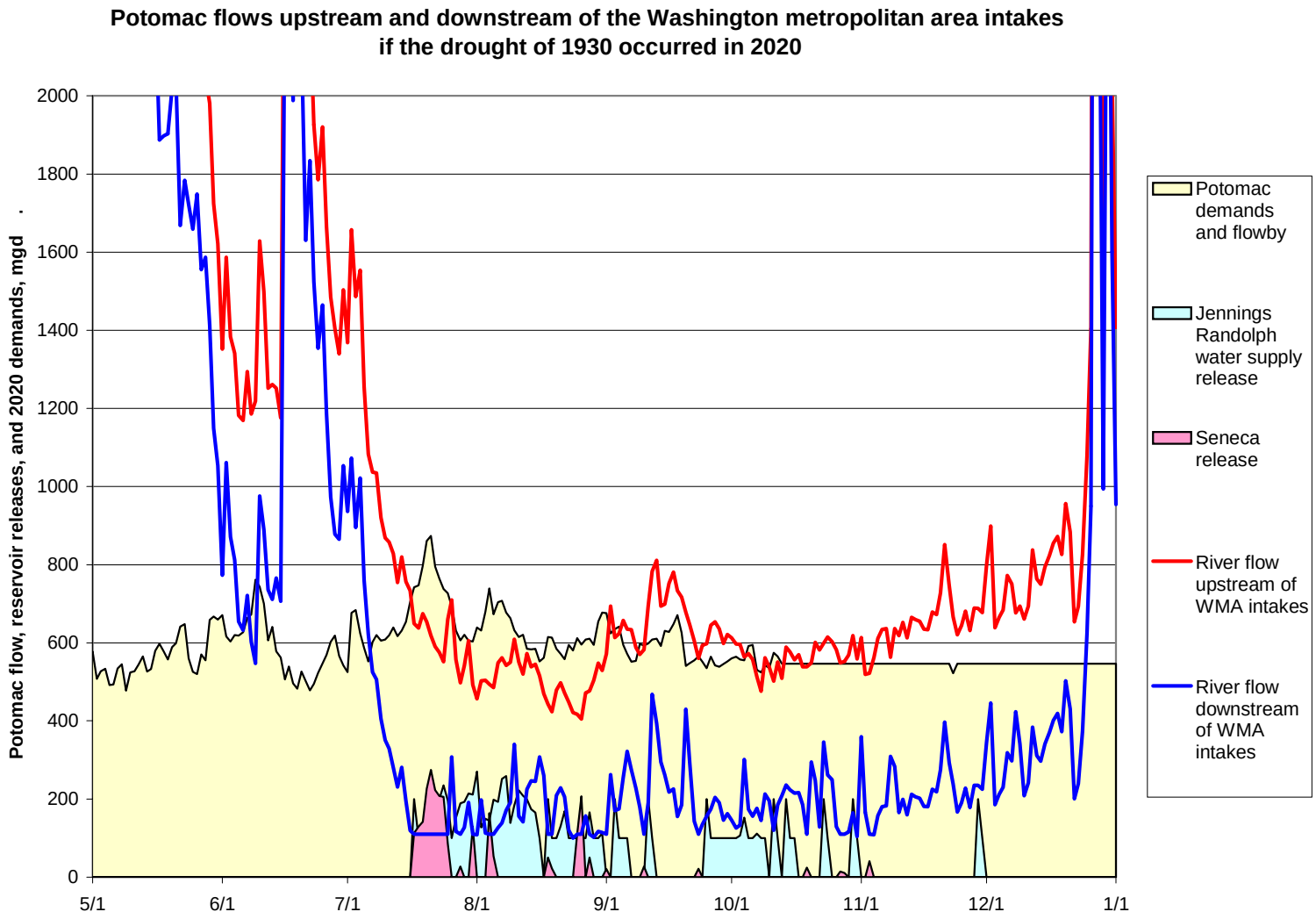

Figure 6-2. Potomac flows upstream and downstream of the WMA water supply intakes if the drought of 1930 occurred in 2020.

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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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